Pit Production Options

Jonathan Medalia
Congressional Research Service
November 20, 2013

Outline

- Background
- Options
- Findings

History

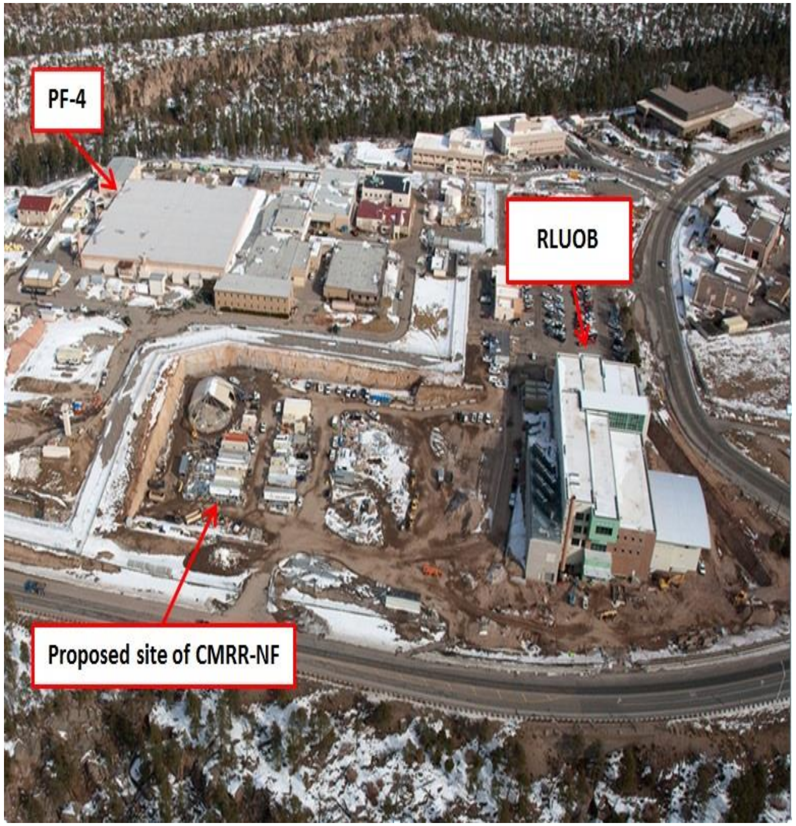
- U.S. has not produced >11 pits/year (ppy) for stockpile since Rocky Flats Plant closed (1989)
- U.S. has built no new Pu buildings for weapons work since 1978 (PF-4)
- Several Pu buildings have been proposed, planned, designed, or built, then canceled, deferred, ignored, or torn down
  - Nuclear Materials Storage Facility, Bldg. 371

Production Capacity

- Current capacity: ~10 pits per year (ppy)
- NWCouncil: 50-80 ppy by 2030
- UCS: 50 ppy max, possibly 10-20 ppy
- LASG: May need no new pits but some capability
- Congress: Assess requirements from 10 to 80+
- Depends on pit life, pit reuse, military requirements, stockpile size, etc.
- Briefing assumes requirement of 80 ppy by 2030
  - Focus: how to achieve 80, not need for 80

Existing Pu Buildings

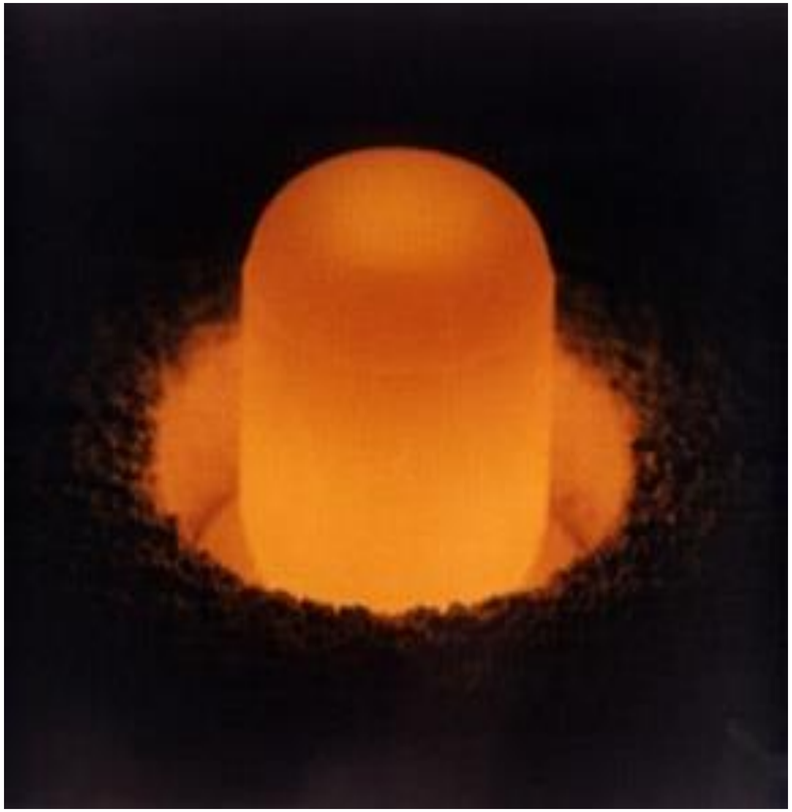
At Los Alamos National Laboratory



Chemistry and Metallurgy Research facility

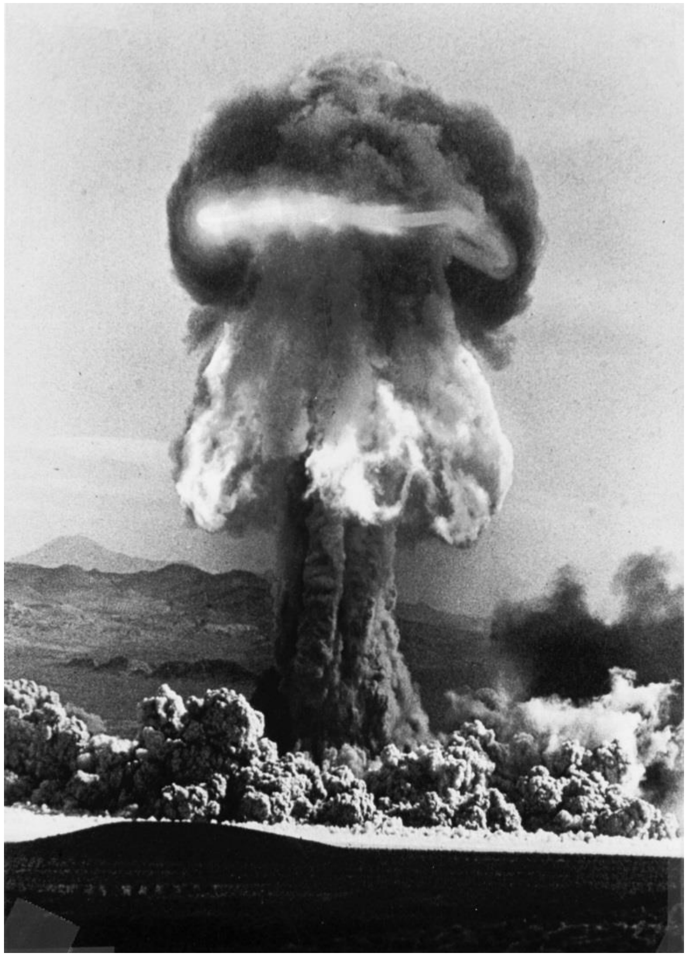
Source: Los Alamos National Laboratory

Pu-238 and Pu-239



Not for pits; high radioactivity

Source for both graphics: DOE



For pits; much lower radioactivity (before detonation)

Regulatory Terms: The Key to Understanding Options

- Dose
  - Units: rem
    - 1-25 rem: no detectable clinical effects*
    - 25-100 rem: serious effects improbable*
- Material At Risk (MAR)
  - Units: grams Pu-239 equivalent
- Hazard Category, Radiological Facility
- Documented Safety Analysis: limits MAR
- Security Category

*Dade Moeller, *Environmental Health,* revised edition, Cambridge, Harvard University Press, 1997, p. 250.

Some Options

- Pit production & supporting work only in PF-4
  - Would have to move out many other tasks to release space and MAR
  - Where would they go? Conseqs for ctr of excellence?
- Build CMRR-NF
  - Deferred; cost, schedule would increase
- New PF-4 + CMRR-NF combo
  - High cost, not designed, long time to design & build
  - Exits PF-4 before end of useful life
- Refurbish CMR
  - Decrepit; 1/36 chance of collapse in 10 yrs in quake

A Structured Approach to Options

	Hazard Category (HC)	
Security Category (SC)	**High (HC-2)**	**Low (HC-3)**
High (SC-I/II)	**Task:** Pit destruction (ARIES) and casting **Buildings:** PF-4 or module (new)	**null set** (no Pu tasks require this combination of attributes)
Low (SC-III/IV)	**Task:** Pu-238 work **Buildings:** HB Line, H Canyon, PTPF (new) at SRS; Building CPP-1634 (expanded) at INL; module at LANL (new)	**Task:** AC **Buildings:** RLUOB with 1 kg WGPu, Building 332 at LLNL*

Source: CRS

*Building 332 is SC-III/HC-2. It is included in this box because the AC tasks discussed here are only HC-3.

Key Point:

Moving MAR & AC out of PF-4

& Keeping Added AC out

May Enable PF-4 to Produce 80 ppy

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Task: Pit Casting & Destruction

- Need high MAR and high security
- PF-4
  - Has needed combination
  - Must reduce other MAR for 80 ppy to stay within DSA limit
  - Must free up space
- Modules: another possibility

Task: Pit Work Outside PF-4

- Modules
  - Description
    - 3,000-5,000 sq ft reinforced-concrete structures
      - Vs. 60,000 sf for PF-4, 19,500 sf for RLUOB
    - Buried near PF-4 and RLUOB
    - Connected to them by tunnel
    - Would use PF-4 infrastructure
    - Each for a single purpose
    - In preliminary planning stage only

Module Pros

- Pros
  - “Big box” approach has proven unsustainable
    - Too ambitious AND too cautious, and too expensive
  - Could build “small boxes” faster, cheaper, as needed
  - Each module would draw on lessons learned from previous modules, saving time and cost
  - Would permit a steady level of funding
  - With each module single-purpose, could match requirements for HC, SC, etc. to the purpose
  - Avoid replacing PF-4

Module Cons

- Are they needed?
  - Could other options do the needed tasks?
    - E.g., moving Pu-238 and Analytic Chem (AC) out of PF-4
- Are they needed now?
- Would they be expensive?
  - Would it be faster and less costly to upgrade PF-4 and move Pu-238 and AC to existing buildings?
- Can Congress have confidence in forthcoming cost and schedule projections?

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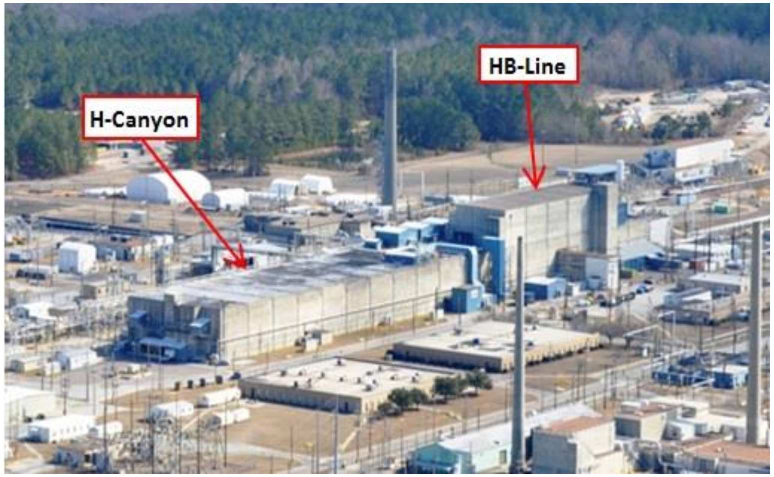
Task: Pu-238 Work Outside PF-4

- Used for RTGs, not pits; low security
- 275x as radioactive as Pu-239; 40% of PF-4 MAR
- Now done in PF-4
  - Moving it out would save space, reduce MAR
- Options: INL , SRS, Module
- Considered earlier; weapon program involvement might change calculus

Source: Idaho National Laboratory



Source: Savannah River Site

A Structured Approach to Options

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Task: Analytic Chemistry (AC)

- Examines composition of Pu in pits
  - Check quantities of trace elements and alloys
  - Check isotopic composition of Pu
  - AC used for all Pu programs, not just pits
- Done at all stages of manufacturing
- Typically uses tiny samples (mg) of Pu
- Low security and low MAR
- But space-intensive
  - Increases (not linearly) with ppy

Building 332 at LLNL

Source: Lawrence Livermore National Laboratory

AC Option: Building 332

- Has ample space suitable for AC
- Could probably do AC for 80 ppy
  - Samples would be sent from LANL
  - AC not time-critical
  - But need steady flow of samples to stay within SC limits
- But would sample flow be steady?
- LLNL would add Pu analytic chemists; it has 4
- Having LLNL do all AC would increase expertise at LLNL at expense of LANL; is that a + or - ?

Radiological Laboratory-Utility-Office Building (RLUOB) at LANL

Source: Los Alamos National Laboratory

AC Option: RLUOB As Is

- RLUOB is well configured for AC
- Ample floor space, excellent ventilation sys

- But it is a Radiological Facility
  - Can hold 26 grams of weapons-grade Pu

Source: Los Alamos National Laboratory

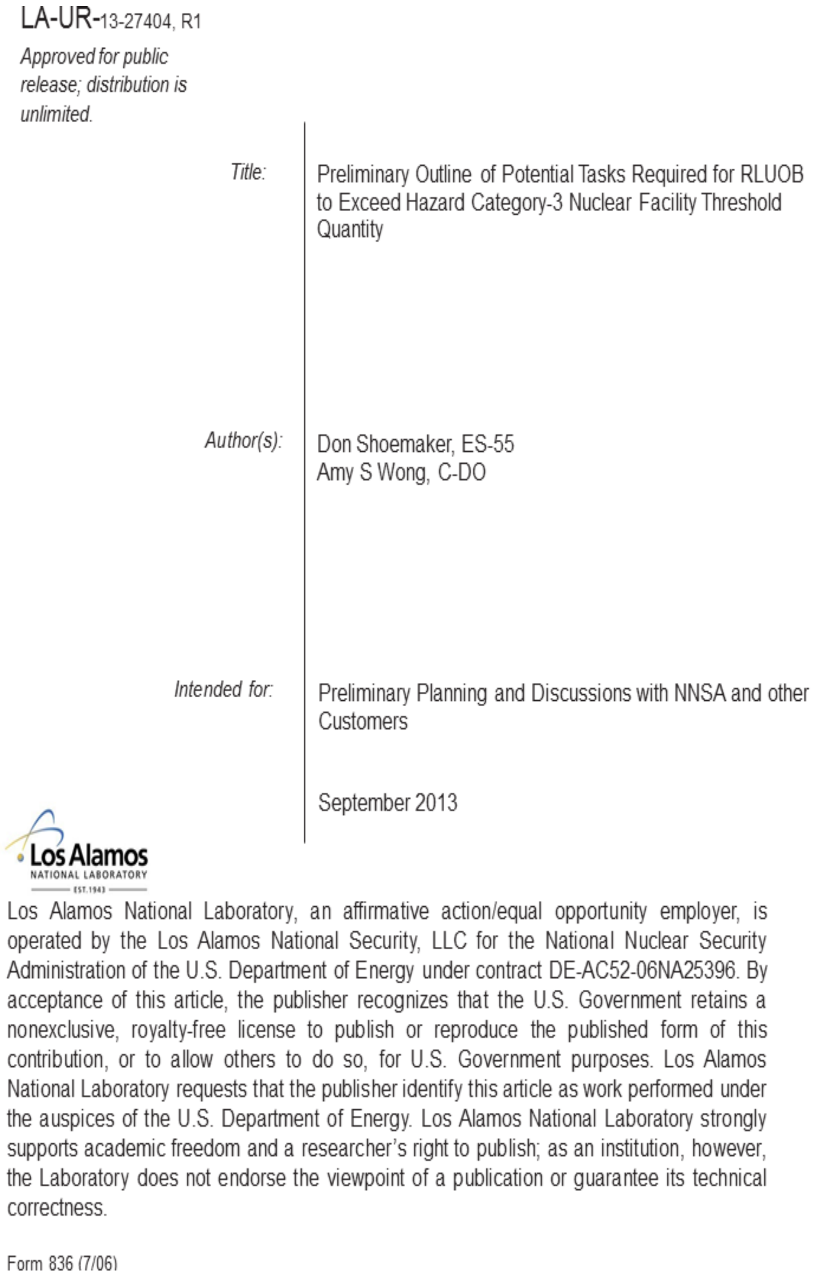
Volume of 26g Weapons-Grade Pu

Not nearly enough to do AC for 80 ppy

Source: CRS

AC Option: RLUOB as HC-3

- RLUOB with 1,000 g WGPu could almost certainly do AC for 80 ppy
- To comply with regs, would convert to HC-3
- This is effectively impossible
  - Many compliance tasks (~100) … see next slides
  - Many are “paperwork”
  - But many “paper” tasks lead to physical tasks



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Approved for public release; distribution is unlimited.

Title: Preliminary Outline of Potential Tasks Required for RLUOB to Exceed Hazard Category-3 Nuclear Facility Threshold Quantity

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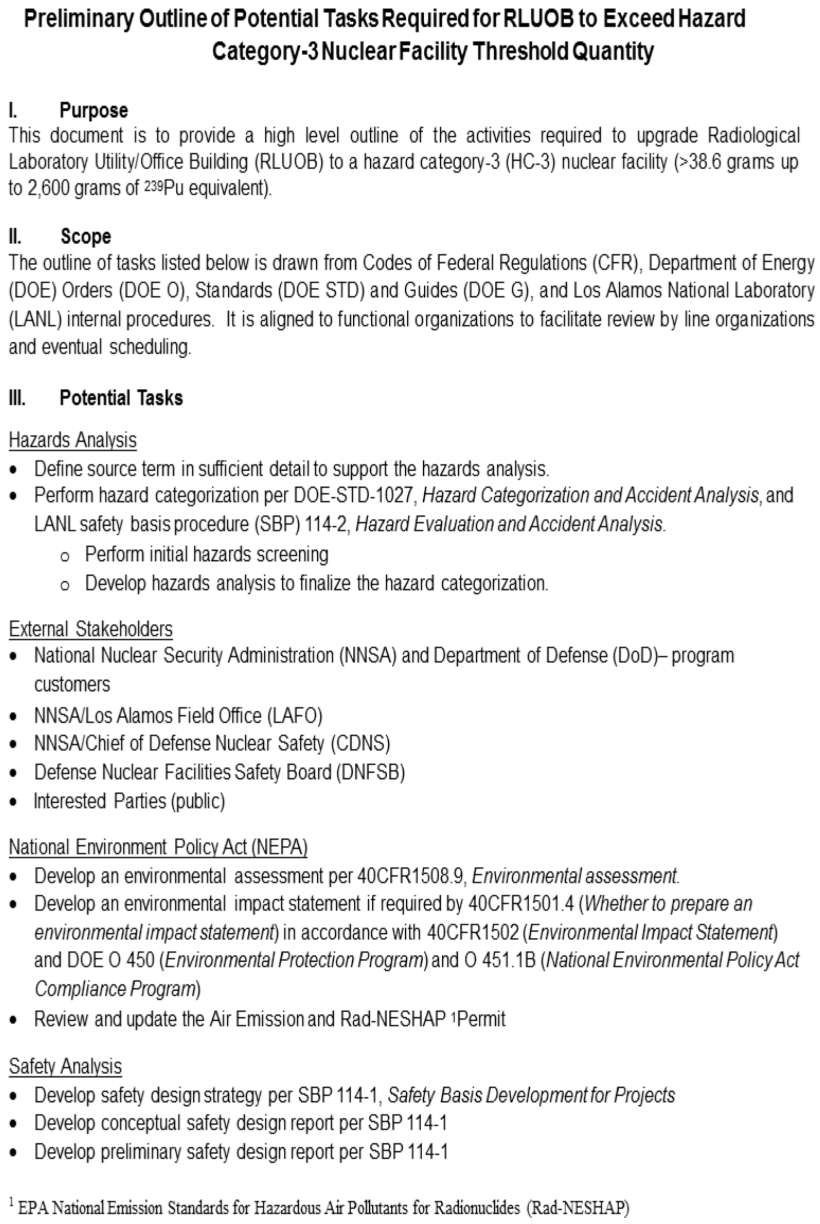
Intended for: Preliminary Planning and Discussions with NNSA and other Customers

September 2013



Preliminary Outline of Potential Tasks Required for RLUOB to Exceed Hazard Category-3 Nuclear Facility Threshold Quantity

I. Purpose

This document is to provide a high level outline of the activities required to upgrade Radiological Laboratory Utility/Office Building (RLUOB) to a hazard category-3 (HC-3) nuclear facility (>38.6 grams up to 2,600 grams of ^{239}Pu equivalent).

II. Scope

The outline of tasks listed below is drawn from Codes of Federal Regulations (CFR), Department of Energy (DOE) Orders (DOE O), Standards (DOE STD) and Guides (DOE G), and Los Alamos National Laboratory (LANL) internal procedures. It is aligned to functional organizations to facilitate review by line organizations and eventual scheduling.

III. Potential Tasks

Hazards Analysis

- Define source term in sufficient detail to support the hazards analysis.
- Perform hazard categorization per DOE-STD-1027, *Hazard Categorization and Accident Analysis*, and LANL safety basis procedure (SBP) 114-2, *Hazard Evaluation and Accident Analysis.*
    - Perform initial hazards screening
    - Develop hazards analysis to finalize the hazard categorization.

External Stakeholders

- National Nuclear Security Administration (NNSA) and Department of Defense (DoD)– program customers
- NNSA/Los Alamos Field Office (LAFO)
- NNSA/Chief of Defense Nuclear Safety (CDNS)
- Defense Nuclear Facilities Safety Board (DNFSB)
- Interested Parties (public)

National Environment Policy Act (NEPA)

- Develop an environmental assessment per 40CFR1508.9, *Environmental assessment.*
- Develop an environmental impact statement if required by 40CFR1501.4 (*Whether to prepare an environmental impact statement*) in accordance with 40CFR1502 (*Environmental Impact Statement*) and DOE O 450 (*Environmental Protection Program*) and O 451.1B (*National Environmental Policy Act Compliance Program*)
- Review and update the Air Emission and Rad-NESHAP [1]Permit

Safety Analysis

- Develop safety design strategy per SBP 114-1, *Safety Basis Development for Projects*
- Develop conceptual safety design report per SBP 114-1
- Develop preliminary safety design report per SBP 114-1

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[1] EPA National Emission Standards for Hazardous Air Pollutants for Radionuclides (Rad-NESHAP)

- Develop documented safety analysis (DSA) and technical safety requirements (TSR)[2] per DOE- STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis* and per SBP 114-1

  Note: These documents are not different documents, but evolutionary stages in the documentation of the safety basis.

Engineering

- Develop system adequacy analysis per Engineering Administrative Procedure (AP)-341-515
- Develop safety design report per DOE-STD-1189, *Integration of Safety into the Design Process.*
- Develop preliminary safety design report per DOE STD 1189.
- Identify vital safety systems per AP-341-101
- Determine critical characteristics for design of safety related items per AP-341-607
- Perform commercial grade dedication per AP-341-703
- Develop functions and requirements documents per AP-341-601
- Develop requirements and criteria document per AP-341-602
- Identify and procure critical spare parts per AP-341-521
- Develop instrument set point calculations per AP-341-613
- Develop software change packages per AP-341-507
- Develop management level determinations per AP-341-502
- Update master equipment list per AP-341-404
- Maintain technical baseline per AP-341-616
- Develop system procurement specifications per AP-341-609 and 610 as required
- Develop design and analysis for seismic upgrades as required. RLUOB safety Structure, System and Components (SSCs) are not currently required to be operational following a seismic event per LAFO direction.
- Develop design and analysis for fire protection upgrades as required
- Develop design, analysis and procurement documentation for building out new laboratory modules (i.e. gloveboxes and hoods) as required
- Review and approve detailed system and equipment design
- Develop test procedures to re-commission existing systems and commission new systems Per Engineering Standard Manual (ESM) chapter 15
- Implement International Building Code (IBC) per ESM chapter 16 for required modifications
- Update pressure safety certifications per ESM chapter17 for new or upgraded systems
- Identify new component labels and tags
- Update record drawings/develop as-built drawings

Fire Protection

- Identify major fire scenarios and special fire considerations for input to likely SSC designation

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[2] TSR is the ~~minimum set of requirements to~~ keep nuclear facility in safe operations based on each nuclear facility's documented safety analysis.

- Develop updated Fire Hazards Analysis per DOE G 151.1-1 *Emergency Management Guide*, DOE O 420.1, *Facility Safety*, DOE O 440.1, *Worker Safety and Health Program for DOE*, DOE G 420.1-3, *Implementation Guide for DOE Fire Protection and Emergency Services Programs for Use with DOE O 420.1B, Facility Safety*, and 10CFR851, *Worker Safety and Health Program.*
- Update fire barrier design and fire areas if needed
- Determine required fire protection system modifications such as a diesel driven fire pump and fire water storage tank.
- Perform Fire Marshall reviews and inspections

Criticality Safety

- Determine criticality potential and develop input to hazard categorization per DOE O 420.1B, DOE STD-3007, *DOE Standard Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities*, and DOE G 421.1-1, *Criticality Safety Good Practices Program Guide for DOE Nonreactor Nuclear Facilities.*
- Develop criticality control philosophy and criticality guidance for design
- Develop updated criticality design requirements during preliminary design
- Update criticality limits and controls during detailed design
- Incorporate criticality controls into TSRs and operating procedures.
- Develop critical safety evaluation document and safety limits for operations

Radiation Protection

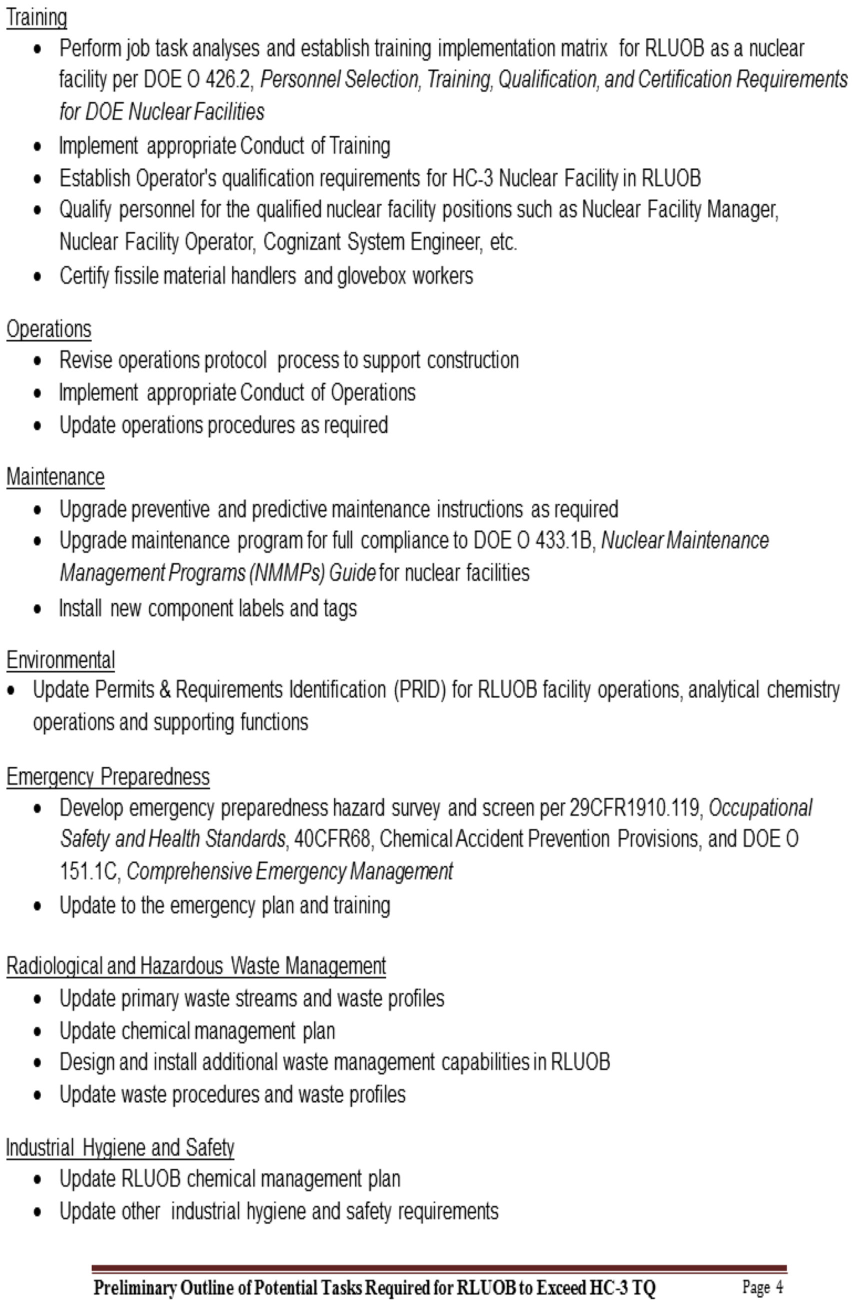
- Develop As Low As Reasonably Achievable (ALARA) strategy per 10CFR835, *Occupational Radiation Protection* and DOE G 441.1-1B, *Radiation Protection Program Guide*
- Perform preliminary shielding analysis considering material location and quantity
- Develop ALARA considerations in design
- Identity contamination control upgrades and zoning
- Develop final shielding analysis
- Develop final ALARA review
- Develop final monitoring plan and procure required monitoring equipment

Quality Assurance (QA)

- Update QA Plan per 10CFR830, *Nuclear Safety Management,* DOE O 414.1C, *Quality Assurance*, and NQA-1, *Nuclear Quality Assurance.*
- Implement added QA requirements
- Perform QA assessments and audits

Security

- Determine and convert uncleared lab area to a secured area is necessary
- Develop draft safeguards requirements identification per DOE O 470.3 *Graded Security Protection Policy* and O 470.4, *Safeguards and Security Program*
- Develop final material control and accountability (MC&A) plan



Training

- Perform job task analyses and establish training implementation matrix for RLUOB as a nuclear facility per DOE O 426.2, *Personnel Selection, Training, Qualification, and Certification Requirements for DOE Nuclear Facilities*
- Implement appropriate Conduct of Training
- Establish Operator's qualification requirements for HC-3 Nuclear Facility in RLUOB
- Qualify personnel for the qualified nuclear facility positions such as Nuclear Facility Manager, Nuclear Facility Operator, Cognizant System Engineer, etc.
- Certify fissile material handlers and glovebox workers

Operations

- Revise operations protocol process to support construction
- Implement appropriate Conduct of Operations
- Update operations procedures as required

Maintenance

- Upgrade preventive and predictive maintenance instructions as required
- Upgrade maintenance program for full compliance to DOE O 433.1B, *Nuclear Maintenance Management Programs (NMMPs) Guide* for nuclear facilities
- Install new component labels and tags

Environmental

- Update Permits & Requirements Identification (PRID) for RLUOB facility operations, analytical chemistry operations and supporting functions

Emergency Preparedness

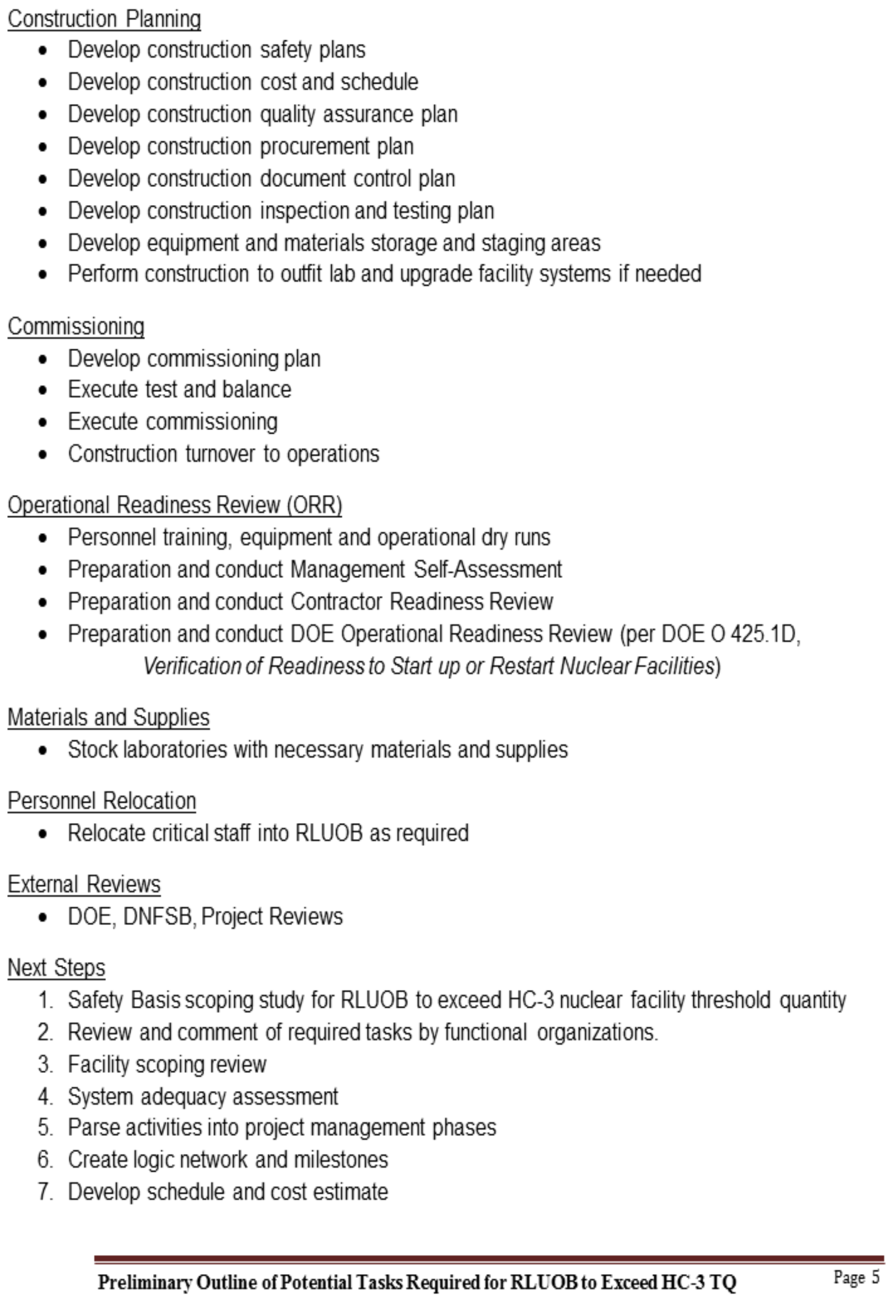
- Develop emergency preparedness hazard survey and screen per 29CFR1910.119, *Occupational Safety and Health Standards*, 40CFR68, Chemical Accident Prevention Provisions, and DOE O 151.1C, *Comprehensive Emergency Management*
- Update to the emergency plan and training

Radiological and Hazardous Waste Management

- Update primary waste streams and waste profiles
- Update chemical management plan
- Design and install additional waste management capabilities in RLUOB
- Update waste procedures and waste profiles

Industrial Hygiene and Safety

- Update RLUOB chemical management plan
- Update other industrial hygiene and safety requirements



Construction Planning

- Develop construction safety plans
- Develop construction cost and schedule
- Develop construction quality assurance plan
- Develop construction procurement plan
- Develop construction document control plan
- Develop construction inspection and testing plan
- Develop equipment and materials storage and staging areas
- Perform construction to outfit lab and upgrade facility systems if needed

Commissioning

- Develop commissioning plan
- Execute test and balance
- Execute commissioning
- Construction turnover to operations

Operational Readiness Review (ORR)

- Personnel training, equipment and operational dry runs
- Preparation and conduct Management Self-Assessment
- Preparation and conduct Contractor Readiness Review
- Preparation and conduct DOE Operational Readiness Review (per DOE O 425.1D, *Verification of Readiness to Start up or Restart Nuclear Facilities*)

Materials and Supplies

- Stock laboratories with necessary materials and supplies

Personnel Relocation

- Relocate critical staff into RLUOB as required

External Reviews

- DOE, DNFSB, Project Reviews

Next Steps

1. Safety Basis scoping study for RLUOB to exceed HC-3 nuclear facility threshold quantity
2. Review and comment of required tasks by functional organizations.
3. Facility scoping review
4. System adequacy assessment
5. Parse activities into project management phases
6. Create logic network and milestones
7. Develop schedule and cost estimate

AC Option: RLUOB with Regulatory Relief

- RLUOB is newest Pu building (2009)
  - Built to higher std than PF-4 (1978) or CMR (1952)
  - Seismic analysis not required for Rad Facility, so no such study has been done
- First floor (lab) is heavily reinforced concrete
- 3 office floors are built to standards of emerg. response bldgs (hospitals, fire stations)
- What dose released if quake collapsed it?

Dose from a Pu Spill and Fire in RLUOB

Type and Quantity (grams) of Pu		Dose (rem) to:	
Pu-239E	**WGPu**	**MOI***	**CW***
38.6	26	0.01	0.27
750	505	0.25	5.20
1,500	1,010	0.49	10.41
2,610	1,760	0.86	18.11
Dept. of Energy standard*		5-25	100

Source: Calculations by Los Alamos National Laboratory

*MOI: maximally exposed offsite individual (at site boundary). CW: collocated worker, 100 meters from building that has released plutonium. Dose standards are from U.S. Department of Energy, DOE Standard: Integration of Safety into the Design Process, DOE-STD-1189-2008, March 2008, pp. A-5, A-6.

Pros

- Reduce risk of design errors (UPF) or cancellation
  - It’s already built
- Reduce risk of schedule slippage, cost growth
- Could be implemented quickly
  - Bldg is outfitted for AC; no rad material yet
- Could exit CMR early
- Cost << new bldg like CMRR-NF ($4B-$6B+)
- Match tasks to buildings
  - Could free up space in PF-4
  - Even with modules, most efficient use of space for AC is in low-SC, low-HC bldg
- Modifying existing bldg minimizes envir. impact

RLUOB Could Be Made More Robust

Source: Stanford Linear
Accelerator Center

Source: Los Alamos National Laboratory

Cons

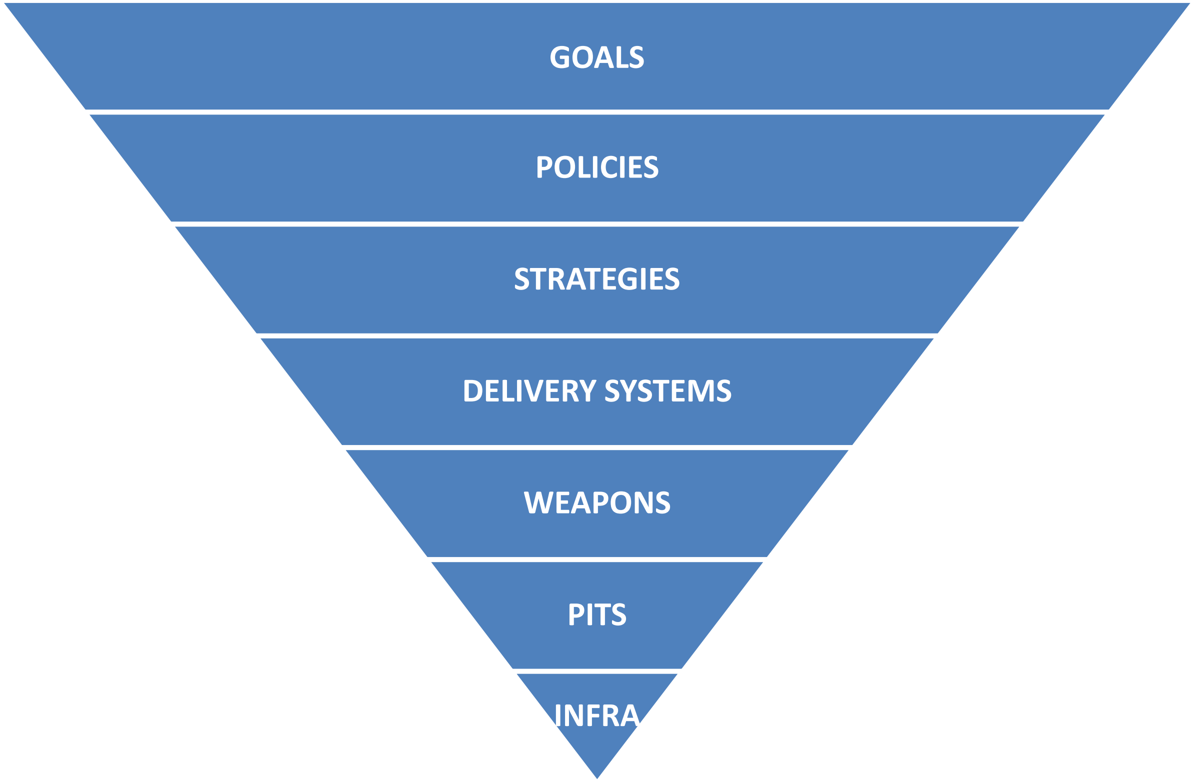
- Office component might collapse in a quake
- Public concern about relaxing nuclear facility standards
- Relaxing standards for one bldg could set precedent for doing so for other projects
- EIS might be inadequate
  - Would it include just RLUOB/PF-4, or also modules, facilities at INL, LLNL, SRS?
- Lab space at LANL for unclassified research on Pu probably disappears

Findings

- There are multiple paths by which NNSA might reach 80 ppy by 2030
- Some paths use existing buildings
  - Likely to reduce risk, cost, delays
- Key: align tasks with buildings
- Doing nothing has costs and risks (CMR)
- Solving 24-year-old pit prod’n problem would enable related programs to move forward

Backup Material

Relationship Between National Goals and Pit Production Infrastructure



GOALS

POLICIES

STRATEGIES

DELIVERY SYSTEMS

WEAPONS

PITS

INFRA

Source: CRS

Security and Hazard Categories for Plutonium

Security Category (SC)	SC for Pu Material Limits		Hazard Category (HC)	HC for Pu-239 Equivalent Material Limits
I	Assembled weapons/test devices; ≥2,000 g pure products*; ≥6,000 g high-grade materials**		(1)	N/A (Nuclear Reactor)
II	Less than SC I, but ≥400 g pure products; ≥2,000 g high-grade materials; ≥16,000 g low-grade materials***		2	>2,610 g Pu-239 Equivalent
III	Less than SC II, but ≥200 g pure products; ≥400 g high-grade materials; ≥3,000 g low-grade materials		3	Less than HC 2, but >38.6 g Pu-239 Equivalent
IV	Less than SC III		(Radiological)†	Less than HC 3

Source: DOE O 474.2 (order), DOE SD G 1027 (supplemental guidance for DOE-STD-1027-92)

A Gas Gun in PF-4

Source: Los Alamos National Laboratory

Sample Calculation for Deriving Dose Values for RLUOB

Factor	Maximally Exposed Offsite Individual (MOI)	Collocated Worker (CW)
MAR (g PE)	500	500
Damage Ratio, DR	1	1
Airborne Release Fraction, ARF*	0.002	0.002
Respirable Fraction, RF	1	1
Leak-Path Factor	1	1
Source Term (g Pu-239 equiv)	1.00	1.00
"Chi over Q," X/Q (s/m^3)	8.77E-05	0.0035
Breathing Rate, BR (m^3/s)	0.00033	0.00033
Specific Activity, SA (Ci/g) for Pu-239 equiv	0.0622	0.0622
Dose Conversion Factor, DCF (rem/Ci)	5.92E+07	3.07E+07
Dose (rem)	0.107	2.21
Dose limit (rem) per DOE regulations	5-25	100

Calculation by Los Alamos National Laboratory. Factors are based on DOE rules except Chi over Q, which is specific to TA-55 (main plutonium area at LANL). Chi over Q includes such factors as distance, wind speed, wind direction, and deposition rate.

*ARF is specific to material form and accident scenario. This factor assumes that all plutonium is in solution, which would be typical of AC material, and a fire. Assuming all plutonium is in solution is conservative, as some material would be in less-vulnerable forms. Source for the factor of 0.002: DOE-Hdbk-3010-94, pg. 3-1.

Thinking Inside the Boxes:

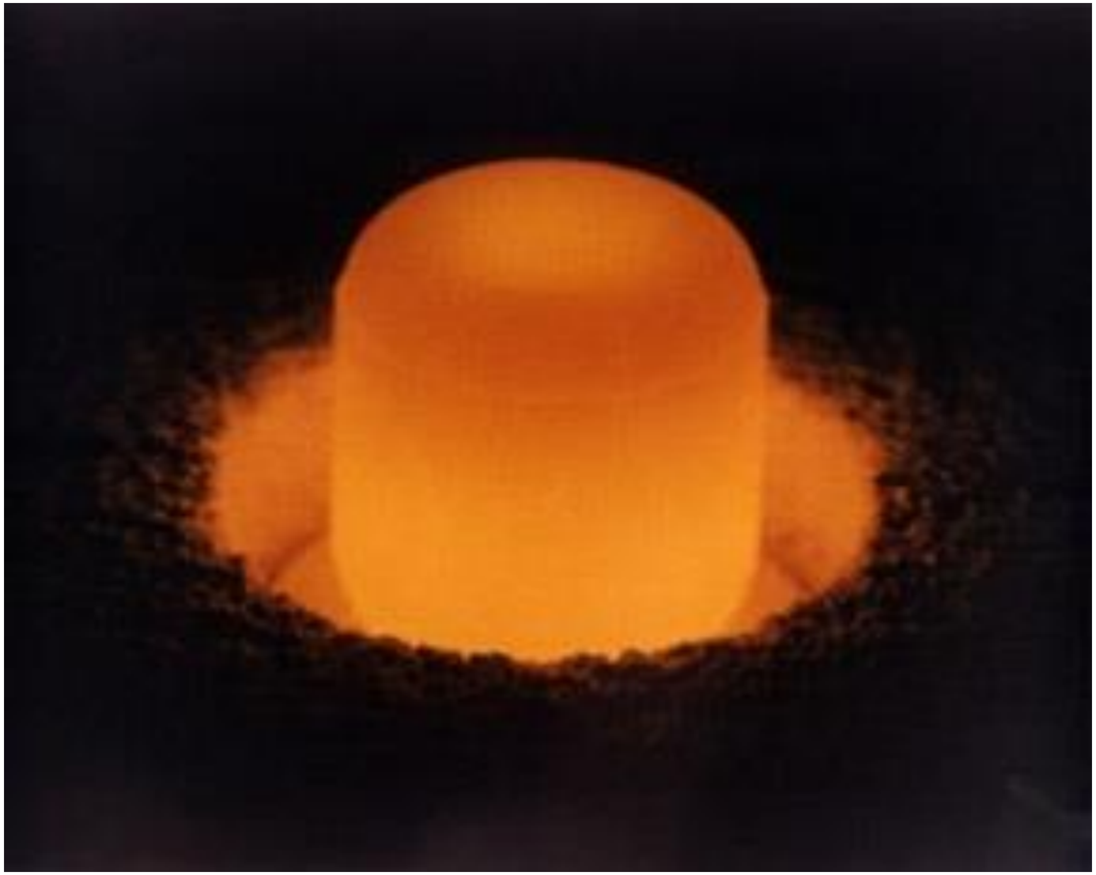
Can Existing Buildings Meet DoD's Pit Needs?

Jonathan Medalia
Congressional Research Service
February 12, 2014

Key Terms

- Material At Risk (MAR)
- Hazard Category
- Radiological Facility
- Security Category
- Analytical Chemistry (AC)
- Plutonium-238 (Pu-238)

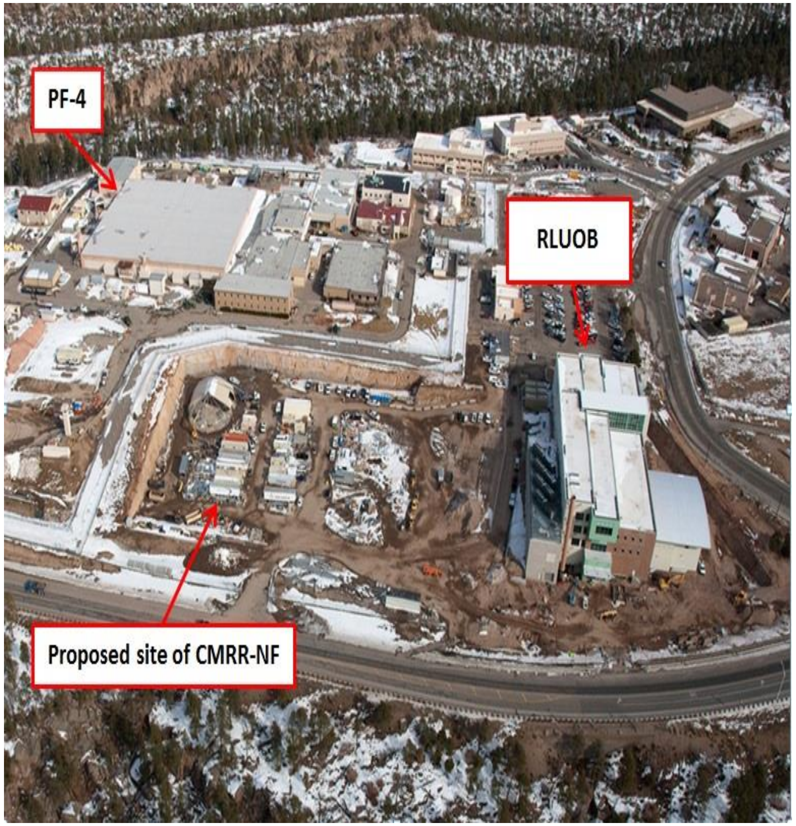
Plutonium-238



Source: Department of Energy

PF-4 and CMR

At Los Alamos National Laboratory



Chemistry and Metallurgy Research facility

Source: Los Alamos National Laboratory

A Framework for Analyzing Options

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Low (SC-III/IV)	**Task:** Pu-238 work **Buildings:** HB Line, H Canyon, PTPF (new) at SRS; Building CPP-1634 (expanded) at INL; module at LANL (new)	**Task:** AC **Buildings:** RLUOB with 1 kg WGPu; Building 332 at LLNL;* F/H Laboratory or Building 773-A at SRS

Source: CRS

*Building 332 is SC-III/HC-2. It is included in this box because the AC tasks discussed here are only HC-3.

Task: Pit Casting (and Destruction)

	Hazard Category (HC)	
Security Category (SC)	**High (HC-2)**	
High (SC-I/II)	**Task:** Pit destruction (ARIES) and casting **Buildings:** PF-4 or module (new)	

Source: CRS

Task: Plutonium-238 Work

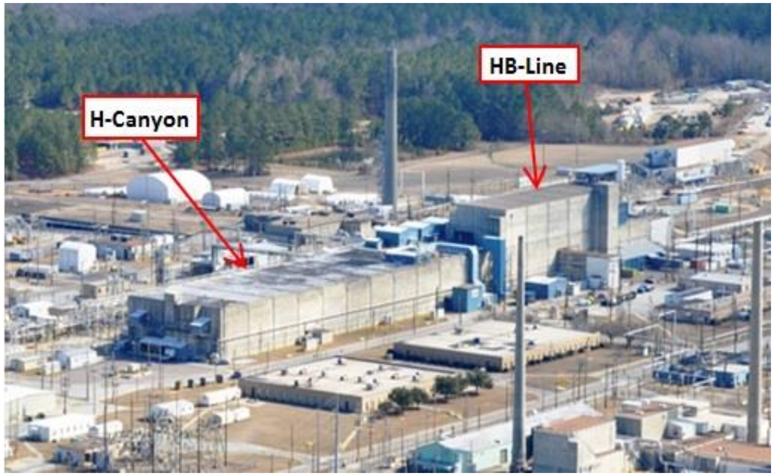
	Hazard Category (HC)	
Security Category (SC)	**High (HC-2)**	
Low (SC-III/IV)	**Task:** Pu-238 work **Buildings:** HB Line, H Canyon, PTPF (new) at SRS; Building CPP-1634 (expanded) at INL; module at LANL (new)	

Source: CRS

Pu-238 Work Outside PF-4

Building CPP-1634
Source: Idaho National Laboratory

H-Canyon and HB-Line
Source: Savannah River Site



Task: Analytical Chemistry

	Hazard Category (HC)	
Security Category (SC)		**Low (HC-3)**
Low (SC-III/IV)		**Task:** Analytical Chemistry **Buildings:** RLUOB with 1 kg WGPu; Building 332 at Livermore;* F/H Laboratory or Building 773-A at Savannah River Site

Source: CRS

*Building 332 is SC-III/HC-2. It is included in this box because the AC tasks discussed here are only HC-3.

Building 332 and F/H Laboratory

Building 332
Source: Lawrence Livermore National Laboratory

F/H Laboratory
Source: Savannah River Site

Radiological Laboratory-Utility-Office Building (RLUOB) at Los Alamos

Source: Los Alamos National Laboratory

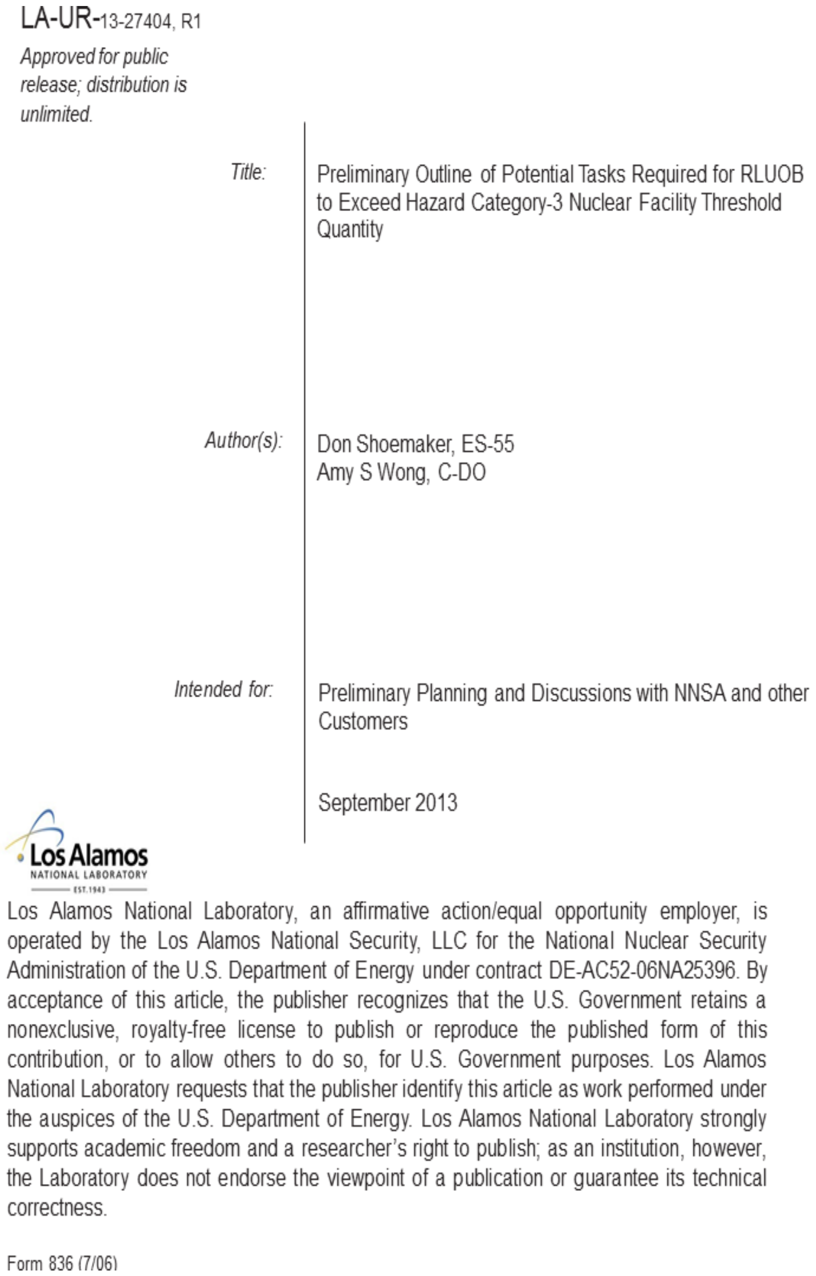
Volume of 26g Weapons-Grade Pu

Not nearly enough to do AC for 80 ppy

Source: CRS

RLUOB Ventilation

Source: Los Alamos National Laboratory



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Title:	Preliminary Outline of Potential Tasks Required for RLUOB to Exceed Hazard Category-3 Nuclear Facility Threshold Quantity
Author(s):	Don Shoemaker, ES-55 Amy S Wong, C-DO
Intended for:	Preliminary Planning and Discussions with NNSA and other Customers September 2013

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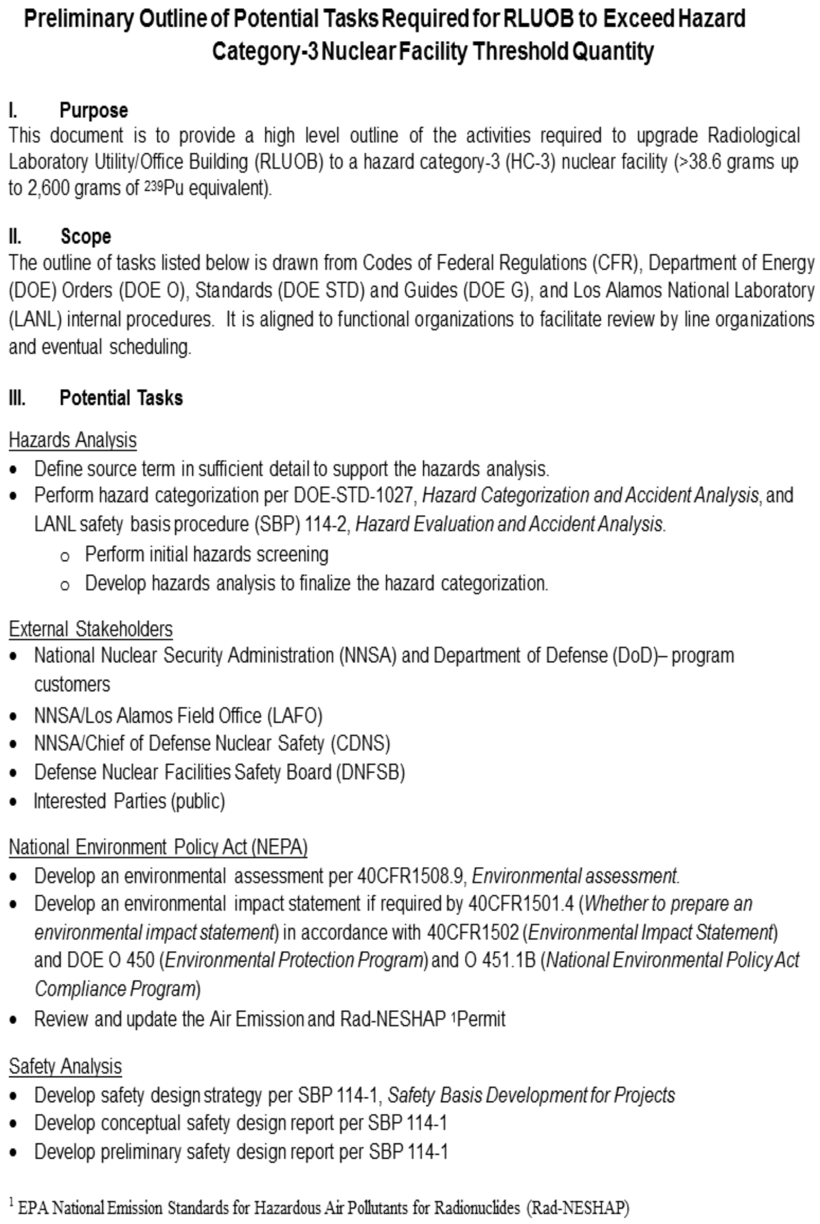


Preliminary Outline of Potential Tasks Required for RLUOB to Exceed Hazard Category-3 Nuclear Facility Threshold Quantity

I. Purpose

This document is to provide a high level outline of the activities required to upgrade Radiological Laboratory Utility/Office Building (RLUOB) to a hazard category-3 (HC-3) nuclear facility (>38.6 grams up to 2,600 grams of ^{239}Pu equivalent).

II. Scope

The outline of tasks listed below is drawn from Codes of Federal Regulations (CFR), Department of Energy (DOE) Orders (DOE O), Standards (DOE STD) and Guides (DOE G), and Los Alamos National Laboratory (LANL) internal procedures. It is aligned to functional organizations to facilitate review by line organizations and eventual scheduling.

III. Potential Tasks

Hazards Analysis

- Define source term in sufficient detail to support the hazards analysis.
- Perform hazard categorization per DOE-STD-1027, *Hazard Categorization and Accident Analysis*, and LANL safety basis procedure (SBP) 114-2, *Hazard Evaluation and Accident Analysis*.
    - Perform initial hazards screening
    - Develop hazards analysis to finalize the hazard categorization.

External Stakeholders

- National Nuclear Security Administration (NNSA) and Department of Defense (DoD)– program customers
- NNSA/Los Alamos Field Office (LAFO)
- NNSA/Chief of Defense Nuclear Safety (CDNS)
- Defense Nuclear Facilities Safety Board (DNFSB)
- Interested Parties (public)

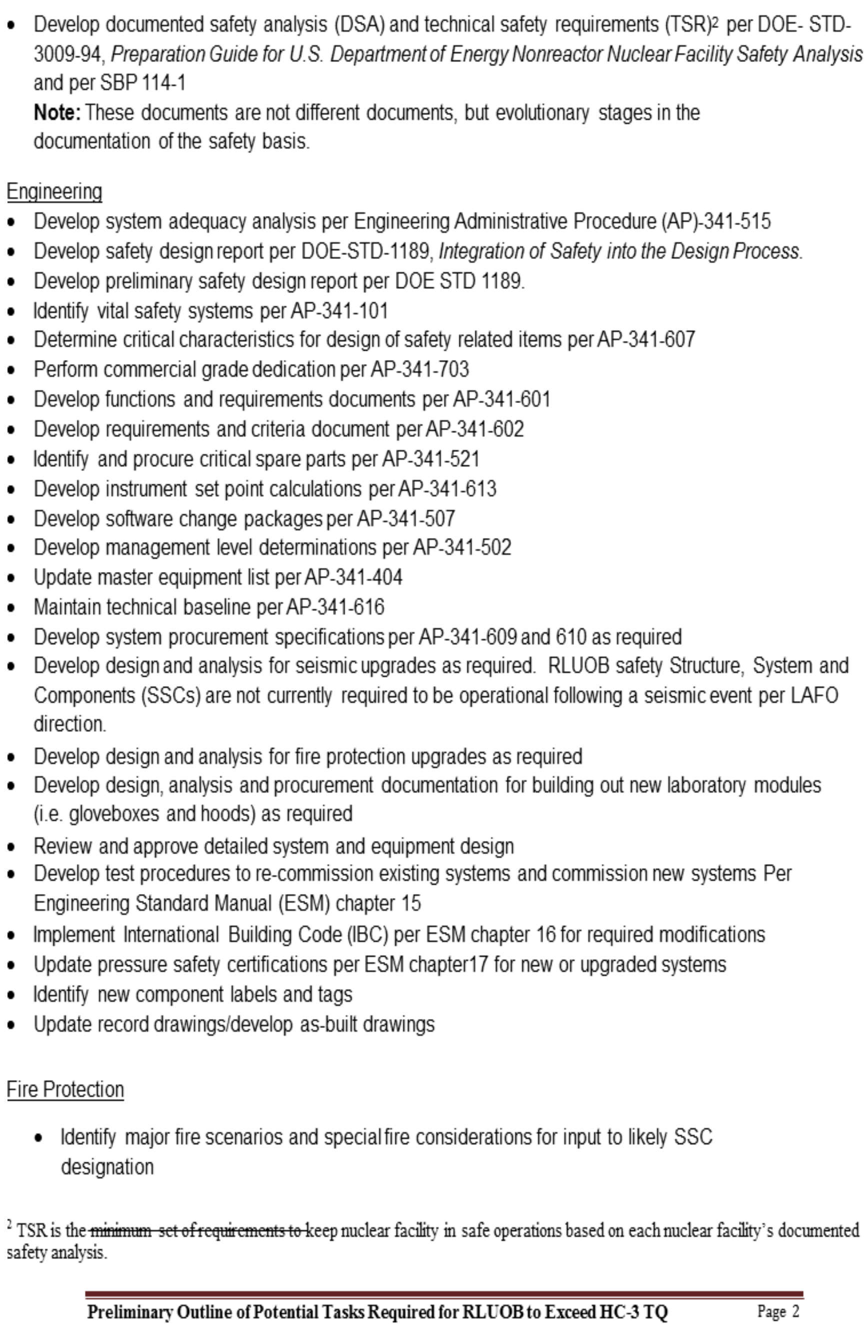
National Environment Policy Act (NEPA)

- Develop an environmental assessment per 40CFR1508.9, *Environmental assessment*.
- Develop an environmental impact statement if required by 40CFR1501.4 (*Whether to prepare an environmental impact statement*) in accordance with 40CFR1502 (*Environmental Impact Statement*) and DOE O 450 (*Environmental Protection Program*) and O 451.1B (*National Environmental Policy Act Compliance Program*)
- Review and update the Air Emission and Rad-NESHAP [1]Permit

Safety Analysis

- Develop safety design strategy per SBP 114-1, *Safety Basis Development for Projects*
- Develop conceptual safety design report per SBP 114-1
- Develop preliminary safety design report per SBP 114-1

[1] EPA National Emission Standards for Hazardous Air Pollutants for Radionuclides (Rad-NESHAP)



- Develop documented safety analysis (DSA) and technical safety requirements (TSR)[2] per DOE- STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis* and per SBP 114-1

  Note: These documents are not different documents, but evolutionary stages in the documentation of the safety basis.

Engineering

- Develop system adequacy analysis per Engineering Administrative Procedure (AP)-341-515
- Develop safety design report per DOE-STD-1189, *Integration of Safety into the Design Process.*
- Develop preliminary safety design report per DOE STD 1189.
- Identify vital safety systems per AP-341-101
- Determine critical characteristics for design of safety related items per AP-341-607
- Perform commercial grade dedication per AP-341-703
- Develop functions and requirements documents per AP-341-601
- Develop requirements and criteria document per AP-341-602
- Identify and procure critical spare parts per AP-341-521
- Develop instrument set point calculations per AP-341-613
- Develop software change packages per AP-341-507
- Develop management level determinations per AP-341-502
- Update master equipment list per AP-341-404
- Maintain technical baseline per AP-341-616
- Develop system procurement specifications per AP-341-609 and 610 as required
- Develop design and analysis for seismic upgrades as required. RLUOB safety Structure, System and Components (SSCs) are not currently required to be operational following a seismic event per LAFO direction.
- Develop design and analysis for fire protection upgrades as required
- Develop design, analysis and procurement documentation for building out new laboratory modules (i.e. gloveboxes and hoods) as required
- Review and approve detailed system and equipment design
- Develop test procedures to re-commission existing systems and commission new systems Per Engineering Standard Manual (ESM) chapter 15
- Implement International Building Code (IBC) per ESM chapter 16 for required modifications
- Update pressure safety certifications per ESM chapter17 for new or upgraded systems
- Identify new component labels and tags
- Update record drawings/develop as-built drawings

Fire Protection

- Identify major fire scenarios and special fire considerations for input to likely SSC designation

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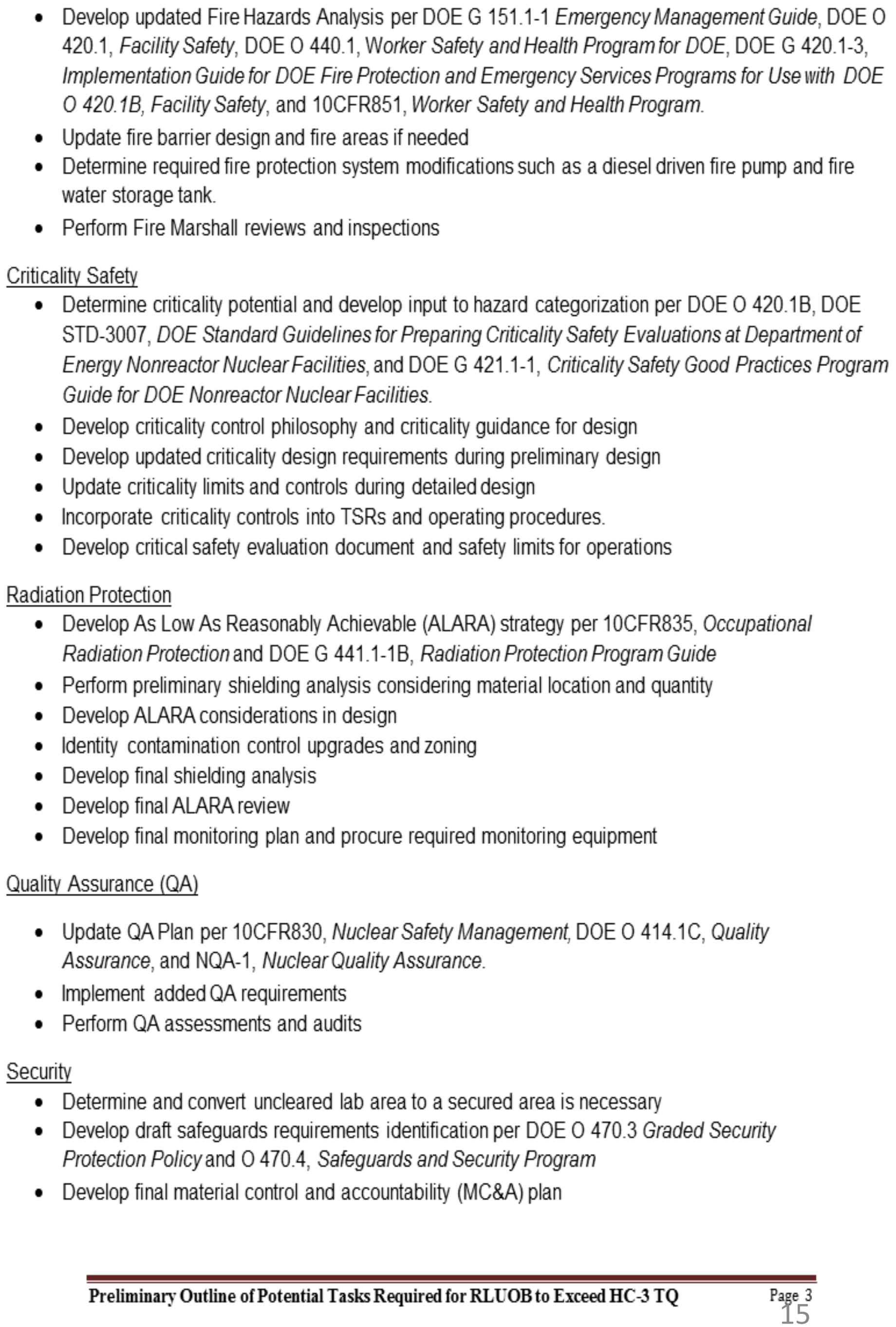
[2] TSR is the ~~minimum set of requirements to~~ keep nuclear facility in safe operations based on each nuclear facility's documented safety analysis.



- Develop updated Fire Hazards Analysis per DOE G 151.1-1 *Emergency Management Guide*, DOE O 420.1, *Facility Safety*, DOE O 440.1, *Worker Safety and Health Program for DOE*, DOE G 420.1-3, *Implementation Guide for DOE Fire Protection and Emergency Services Programs for Use with DOE O 420.1B, Facility Safety*, and 10CFR851, *Worker Safety and Health Program.*
- Update fire barrier design and fire areas if needed
- Determine required fire protection system modifications such as a diesel driven fire pump and fire water storage tank.
- Perform Fire Marshall reviews and inspections

Criticality Safety

- Determine criticality potential and develop input to hazard categorization per DOE O 420.1B, DOE STD-3007, *DOE Standard Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities*, and DOE G 421.1-1, *Criticality Safety Good Practices Program Guide for DOE Nonreactor Nuclear Facilities.*
- Develop criticality control philosophy and criticality guidance for design
- Develop updated criticality design requirements during preliminary design
- Update criticality limits and controls during detailed design
- Incorporate criticality controls into TSRs and operating procedures.
- Develop critical safety evaluation document and safety limits for operations

Radiation Protection

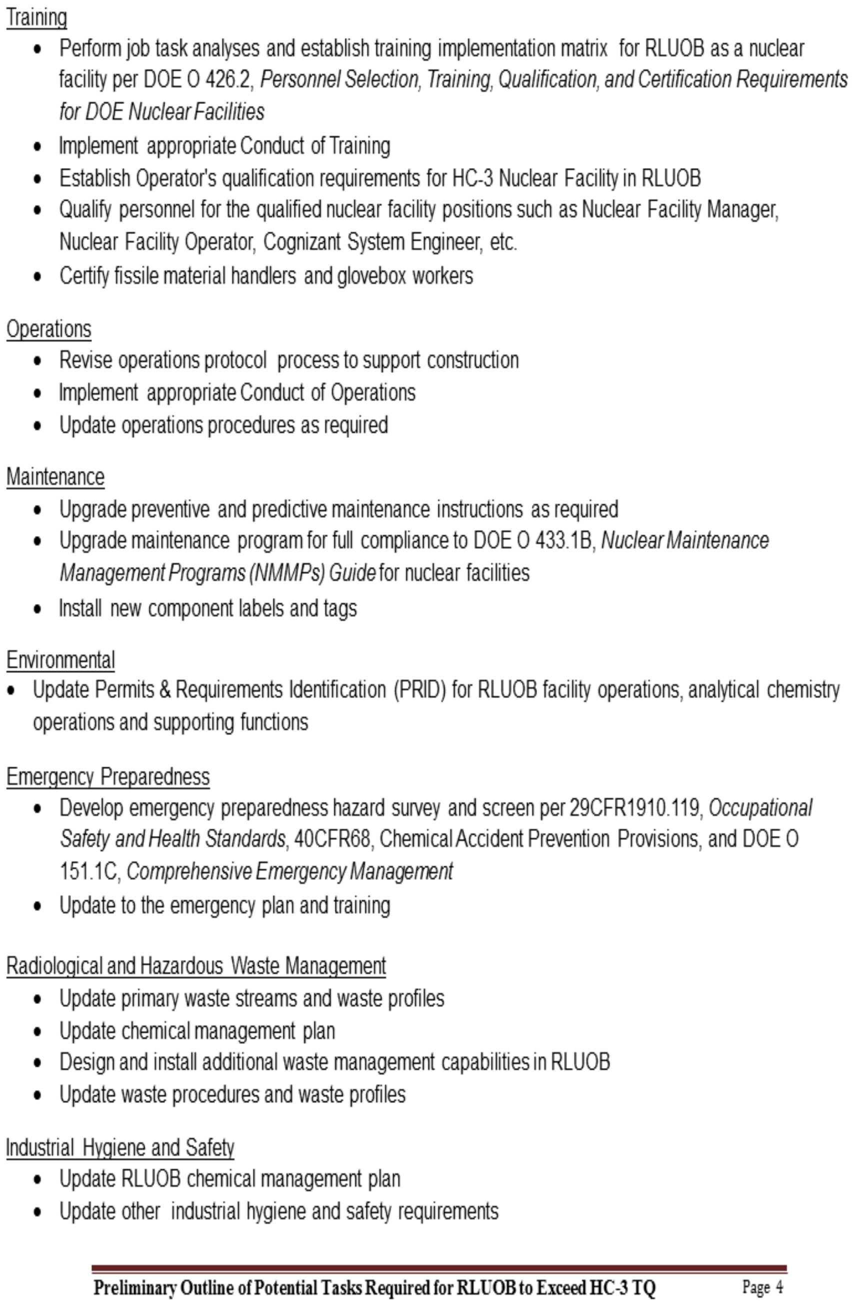
- Develop As Low As Reasonably Achievable (ALARA) strategy per 10CFR835, *Occupational Radiation Protection* and DOE G 441.1-1B, *Radiation Protection Program Guide*
- Perform preliminary shielding analysis considering material location and quantity
- Develop ALARA considerations in design
- Identity contamination control upgrades and zoning
- Develop final shielding analysis
- Develop final ALARA review
- Develop final monitoring plan and procure required monitoring equipment

Quality Assurance (QA)

- Update QA Plan per 10CFR830, *Nuclear Safety Management*, DOE O 414.1C, *Quality Assurance*, and NQA-1, *Nuclear Quality Assurance.*
- Implement added QA requirements
- Perform QA assessments and audits

Security

- Determine and convert uncleared lab area to a secured area is necessary
- Develop draft safeguards requirements identification per DOE O 470.3 *Graded Security Protection Policy* and O 470.4, *Safeguards and Security Program*
- Develop final material control and accountability (MC&A) plan



Training

- Perform job task analyses and establish training implementation matrix for RLUOB as a nuclear facility per DOE O 426.2, *Personnel Selection, Training, Qualification, and Certification Requirements for DOE Nuclear Facilities*
- Implement appropriate Conduct of Training
- Establish Operator's qualification requirements for HC-3 Nuclear Facility in RLUOB
- Qualify personnel for the qualified nuclear facility positions such as Nuclear Facility Manager, Nuclear Facility Operator, Cognizant System Engineer, etc.
- Certify fissile material handlers and glovebox workers

Operations

- Revise operations protocol process to support construction
- Implement appropriate Conduct of Operations
- Update operations procedures as required

Maintenance

- Upgrade preventive and predictive maintenance instructions as required
- Upgrade maintenance program for full compliance to DOE O 433.1B, *Nuclear Maintenance Management Programs (NMMPs) Guide* for nuclear facilities
- Install new component labels and tags

Environmental

- Update Permits & Requirements Identification (PRID) for RLUOB facility operations, analytical chemistry operations and supporting functions

Emergency Preparedness

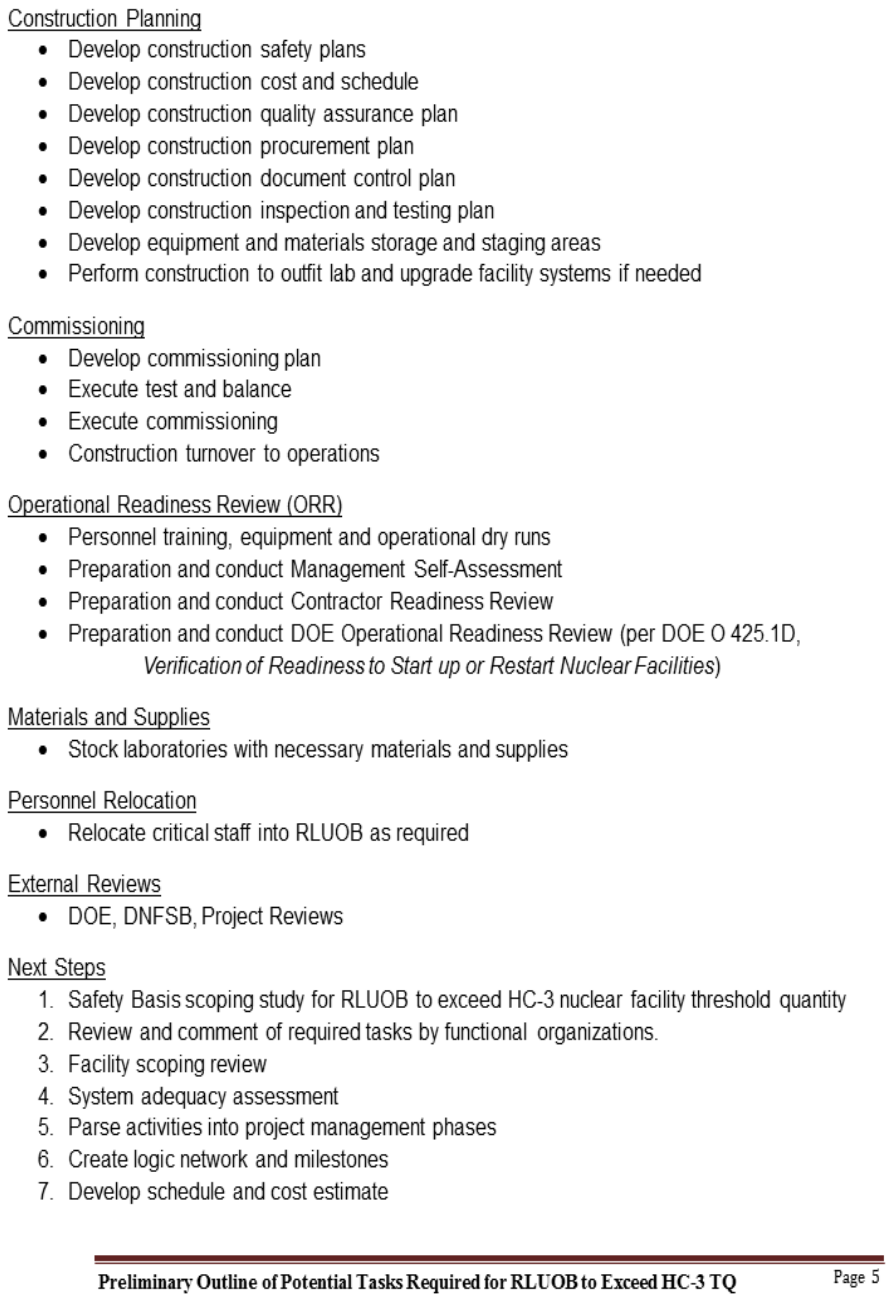
- Develop emergency preparedness hazard survey and screen per 29CFR1910.119, *Occupational Safety and Health Standards*, 40CFR68, Chemical Accident Prevention Provisions, and DOE O 151.1C, *Comprehensive Emergency Management*
- Update to the emergency plan and training

Radiological and Hazardous Waste Management

- Update primary waste streams and waste profiles
- Update chemical management plan
- Design and install additional waste management capabilities in RLUOB
- Update waste procedures and waste profiles

Industrial Hygiene and Safety

- Update RLUOB chemical management plan
- Update other industrial hygiene and safety requirements



Construction Planning

- Develop construction safety plans
- Develop construction cost and schedule
- Develop construction quality assurance plan
- Develop construction procurement plan
- Develop construction document control plan
- Develop construction inspection and testing plan
- Develop equipment and materials storage and staging areas
- Perform construction to outfit lab and upgrade facility systems if needed

Commissioning

- Develop commissioning plan
- Execute test and balance
- Execute commissioning
- Construction turnover to operations

Operational Readiness Review (ORR)

- Personnel training, equipment and operational dry runs
- Preparation and conduct Management Self-Assessment
- Preparation and conduct Contractor Readiness Review
- Preparation and conduct DOE Operational Readiness Review (per DOE O 425.1D, *Verification of Readiness to Start up or Restart Nuclear Facilities*)

Materials and Supplies

- Stock laboratories with necessary materials and supplies

Personnel Relocation

- Relocate critical staff into RLUOB as required

External Reviews

- DOE, DNFSB, Project Reviews

Next Steps

1. Safety Basis scoping study for RLUOB to exceed HC-3 nuclear facility threshold quantity
2. Review and comment of required tasks by functional organizations.
3. Facility scoping review
4. System adequacy assessment
5. Parse activities into project management phases
6. Create logic network and milestones
7. Develop schedule and cost estimate

Dose from a Pu Spill and Fire in RLUOB

Type and Quantity (g) Pu		Dose (rem) to:	
Pu-239E	**WGPu***	**MOI****	**CW****
38.6	26	0.01	0.27
750	505	0.25	5.20
1,500	**1,010**	**0.49**	**10.41**
2,610	1,760	0.86	18.11
Dept. of Energy guideline*		**5-25**	**100**

Source: Calculations by Los Alamos National Laboratory

* Weapons-grade plutonium (WGPu) is more radioactive than Pu-239; 1 g WGPu is as radioactive as 1.48 g Pu-239.

** MOI: maximally exposed offsite individual (at site boundary). CW: collocated worker, 100 meters from building that has released plutonium. Dose standards are from U.S. Department of Energy, DOE Standard: Integration of Safety into the Design Process, DOE-STD-1189-2008, March 2008, pp. A-5, A-6.

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U.S. Nuclear Weapon "Pit" Production Options for Congress

Jonathan E. Medalia
Specialist in Nuclear Weapons Policy

February 21, 2014

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Summary

A "pit" is the plutonium core of a nuclear weapon. Until 1989, the Rocky Flats Plant (CO) mass-produced pits. Since then, the United States has made at most 11 pits per year (ppy). U.S. policy is to maintain existing nuclear weapons. To do this, the Department of Defense states that it needs the Department of Energy (DOE), which maintains U.S. nuclear weapons, to produce 50-80 ppy by 2030. While some argue that few if any new pits are needed, at least for decades, this report focuses on options to reach 80 ppy.

Pit production involves precisely forming plutonium—a hazardous, radioactive, physically quirky metal. Production requires supporting tasks, such as analytical chemistry (AC), which monitors the chemical composition of plutonium in each pit.

With Rocky Flats closed, DOE established a small-scale pit manufacturing capability at PF-4, a building at Los Alamos National Laboratory (LANL). DOE also proposed higher-capacity facilities; none came to fruition. In 2005, Congress rejected the Modern Pit Facility, viewing as excessive the capacity range DOE studied, 125-450 ppy. In 2012, the Administration "deferred" construction of the Chemistry and Metallurgy Research Replacement Nuclear Facility (CMRR-NF) on grounds of availability of interim alternatives and affordability.

Nonetheless, options remain:

- **Build CMRR-NF.** Congress mandated it in the FY2013 cycle, but provided no funds for it then, and permitted consideration of an alternative in the FY2014 cycle.
- **Remove from PF-4 tasks not requiring high MAR and security.** Casting pits uses much plutonium that an accident might release ("Material At Risk," MAR) and requires high security. Making 80 ppy would require freeing more MAR and floor space in PF-4 for casting.
- **Provide regulatory relief so RLUOB could hold 1,000 grams of plutonium with few changes to the building.** AC for 80 ppy needs much floor space but not high MAR or high security. Several options involve LANL's Radiological Laboratory/Utility/Office Building (RLUOB). Regulations permit it to hold 26 grams of weapons-grade plutonium, the volume of two nickels; AC for 80 ppy would require 500 to 1,000 grams and perhaps space elsewhere. Augmenting RLUOB to hold the latter amounts within regulations would be costly even though the radiation dose if the building collapsed would be very low. Regulatory relief would save time and money, but would raise concerns about compliance with regulations. A complementary option is to perform some AC at Lawrence Livermore National Laboratory or Savannah River Site.
- **Move plutonium-238 work to Idaho National Laboratory or Savannah River Site.** Fabricating plutonium-238 into power sources for space probes entails high MAR, but not high security because it is not used in pits. Moving it would free MAR and floor space in PF-4. At issue is whether to conduct all plutonium work at LANL, the plutonium "center of excellence."

- **Build concrete "modules" connected to PF-4.** This would enable high-MAR work to move out of PF-4, so PF-4 and modules could do the needed pit work. At issue: are modules needed, at what cost, and when.

Several options have the potential to produce 80 ppy and permit other plutonium activities at relatively modest cost, in a relatively short time, with no new buildings, and with minimal environmental impact. Determining their desirability and feasibility would require detailed study.

Observations include:

- Differing time horizons between Congress and DOE, and between political and technical imperatives, cause problems.
- Doing nothing entails costs and risks. Keeping a 1950s-era building open while options are explored exposes workers to a relatively high risk of death in an earthquake.
- Congress may wish to consider limiting a building's permitted plutonium quantity by estimated dose instead of MAR. A facility can be safe even if it is not compliant with regulations.
- The political system is more flexible than the regulatory system. Regulations derive their authority from statutes. Regulators, bound by these statutes, cannot make cost-benefit tradeoffs regarding compliance. In contrast, the political system has the authority, ability, and culture to decide which tradeoffs are worth making.

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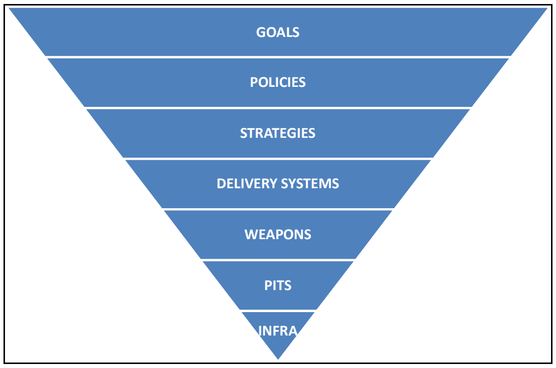
Introduction

Of all the problems facing the nuclear weapons program and nuclear weapons complex over the past several decades, few, if any, have been as vexing as pit production. A "pit" is a hollow plutonium shell that is imploded, creating an explosion that triggers the rest of the weapon. The Rocky Flats Plant (CO) manufactured pits on a large scale during the Cold War until production halted in 1989. It took until FY2007 for the United States to produce even a small quantity, 11 pits per year (ppy), for the stockpile.[1] Yet the Department of Defense (DOD) calls for a capacity to produce 30 ppy by 2021 as an interim goal and 50 to 80 ppy by around 2030. At issue is how to reach the higher capacity.

This report is intended primarily for Members and staff with a direct interest in pit issues, including Members who will be making decisions on pit projects that could total several billion dollars. Since the issues are complicated, this report contains technical and regulatory details that are needed to understand the advantages, drawbacks, and uncertainties of various options. It may also be of value for Members and staff with an interest in nuclear weapons, stockpile stewardship, and nuclear policy more broadly. This report begins with a description of plutonium, pits, and pit factory problems. It next considers several pit production options. It notes studies that could provide information to assist Congress in choosing among options, and concludes with several observations. There are several Appendixes, including a list of abbreviations.

Figure 1. Relationship Between National Goals and Pit Production Infrastructure



Source: CRS.

Note: "Infrastructure" is abbreviated as "infra."

The pit issue is important because of the relationship between pit production infrastructure and national goals, as shown in **Figure 1**. National goals include minimizing the risk of nuclear war and, for the longer term, "the peace and security of a world without nuclear weapons," as President Obama declared in his 2009 Prague speech.[2] The Nuclear Posture Review sets out policy objectives, such as "preventing nuclear proliferation," "reducing the role of U.S. nuclear weapons in U.S. national security strategy," "maintaining strategic deterrence and stability at reduced nuclear force levels," "strengthening regional deterrence," and "sustaining a safe, secure, and effective nuclear arsenal."[3] Various strategies, such as deterrence, counterproliferation, and arms control, seek to implement policy. In turn, delivery systems, such as heavy bombers and long-range ballistic missiles, are one means of implementing strategy. Nuclear weapons (a term used in this report to refer to nuclear bombs and warheads) arm delivery systems. The Nuclear Posture Review declares, "The United States will not develop new

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[1] Information provided by Los Alamos National Laboratory, email, November 13, 2013.

[2] U.S. White House. Office of the Press Secretary. Remarks by President Barack Obama, Hradcany Square, Prague, Czech Republic, April 5, 2009, http://www.whitehouse.gov/the-press-office/remarks-president-barack-obama-prague-delivered.

[3] U.S. Department of Defense. *Nuclear Posture Review Report,* April 2010, p. iii, http://www.defense.gov/npr/docs/2010%20nuclear%20posture%20review%20report.pdf.

nuclear warheads."[4] Accordingly, the United States will retain the weapons in its arsenal for the foreseeable future. Yet weapons deteriorate over time. Extending the service life of existing weapons requires replacing or modifying some components. While "life extension programs" (LEPs) for some weapons can use existing pits, DOD and the Department of Energy (DOE) state that LEPs for other weapons will require newly-manufactured pits. The current infrastructure cannot produce pits at the capacity DOD requires, and many efforts stretching back to the late 1980s to produce pits have been canceled or have otherwise foundered. A concern is that if a type of nuclear weapon could no longer perform satisfactorily, an inability to make new pits in the quantities required so the weapons could be replaced could lead to that weapon type being removed from service. That, in turn, would leave missiles and bombers without those weapons, which would undermine strategies, the policies they seek to implement, and the ability to attain national goals.

Background

This section begins by discussing plutonium, pits, pit production, programs to extend the service life of nuclear weapons, and production capacity required. It next turns to current plutonium facilities and provides a brief history of unsuccessful efforts to build a facility to produce pits on a scale larger than about 10 per year. It concludes by presenting important regulatory terms.

Technical Aspects

Plutonium

Plutonium is a radioactive metal that is 1.75 times more dense than lead. It has several undesirable characteristics, and is difficult to work with. According to Siegfried Hecker, a plutonium metallurgist and a former director of Los Alamos National Laboratory (LANL),

> Plutonium is an element at odds with itself—with little provocation, it can change its density by as much as 25 percent; it can be as brittle as glass or as malleable as aluminum; it expands when it solidifies; and its freshly-machined silvery surface will tarnish in minutes, producing nearly every color in the rainbow. To make matters even more complex, plutonium ages from the outside in and from the inside out. It reacts vigorously with its environment—particularly with oxygen, hydrogen, and water—thereby, degrading its properties from the surface to the interior over time. In addition, plutonium's continuous radioactive decay causes self-irradiation damage that can fundamentally change its properties over time.[5]

To make plutonium more stable, it is typically alloyed with other materials, such as gallium.[6]

Handling and safeguarding plutonium poses significant risks. Plutonium is hazardous: if minute particles are inhaled and lodge in the lungs, their radiation (in the form of alpha particles) can cause lung cancer. In addition, terrorists might be able to build an improvised nuclear device if

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[4] Ibid., p. 39.

[5] Siegfried Hecker, "Plutonium and Its Alloys: From Atoms to Microstructure," *Los Alamos Science*, vol. 26 (2000), p. 291, http://www.fas.org/sgp/othergov/doe/lanl/pubs/00818035.pdf. For additional information on plutonium, see Argonne National Laboratory, Environmental Science Division, "Plutonium," Human Health Fact Sheet, August 2005, 2 p., http://www.evs.anl.gov/pub/doc/Plutonium.pdf.

[6] "The Plutonium Challenge," *Los Alamos Science,* no. 26, 2000, p. 25.

they were to obtain enough plutonium, so facilities holding more than a small quantity of certain plutonium isotopes require extremely high security.

Plutonium does not occur in nature except in trace amounts. It is manufactured by exposing uranium fuel rods to neutrons in nuclear reactors, and then using chemical processes to separate it from other elements in the fuel rods. The result is a mix of plutonium isotopes. The isotope desired for nuclear weapons is plutonium-239, which fissions readily when struck by slow or fast neutrons. Weapons-grade plutonium (WGPu) consists mainly of plutonium-239 and a small fraction of other plutonium isotopes. (Note: When an isotope of plutonium is mentioned, such as plutonium-239, it is abbreviated using its chemical symbol, e.g., Pu-239.)

Pits

A pit is the trigger for detonating a thermonuclear weapon, or hydrogen bomb. It is a hollow shell of plutonium and other materials surrounded by chemical explosives. When the explosives detonate, they create an inward-moving pressure wave (an implosion wave) that compresses the plutonium enough to make it supercritical. It undergoes a runaway fission chain reaction, i.e., an explosion. Various means are used to augment the explosion. This part of the weapon is called the primary stage. The weapon is designed so that energy from the primary stage explosion implodes the weapon's secondary stage, in which nuclear fission and fusion release most of the weapon's total explosive force.

While some pits in older weapons were made of uranium and plutonium ("composite pits"), modern pits use only plutonium because much less of that material is required to generate a given explosive force, permitting nuclear weapons to be smaller and lighter. Reducing the size and weight of weapons was important during the Cold War to maximize the number of weapons that could be fitted on a missile and to maximize the explosive force of a weapon of given weight. All nuclear weapons in the current U.S. nuclear stockpile were designed and tested during the Cold War; all but a handful were built during that time.

Because plutonium decays radioactively, there was concern that pits could deteriorate in ways that would cause them to fail. However, several studies have projected increased pit life. In 2003, pit life was thought to be 45-60 years;[7] a 2007 study placed life for most pits at over 100 years;[8] and a 2012 Livermore study placed the figure at 150 years.[9] A 2013 Los Alamos study raised uncertainties on the latter claim:

> Since 2006, plutonium aging work has continued at a low level. That research does not indicate any [e]ffects that would preclude the possibility of pit reuse. However, additional studies that had been planned were never undertaken, leaving some aging questions unanswered for the range of plutonium alloys in the stockpile, and for the potential applications of pit reuse now under consideration.[10]

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[7] U.S. Department of Energy. National Nuclear Security Administration, Draft Supplemental Programmatic Environmental Impact Statement on Stockpile Stewardship and Management for a Modern Pit Facility, Summary volume, DOE/EIS-236-S2, Washington, DC, May 2003, pp. S-12, http://energy.gov/sites/prod/files/EIS-0236-S2-DEIS-Summary-2003_1.pdf.

[8] R.J. Hemley et al., *Pit Lifetime*, The MITRE Corporation, JASON Program Office, JSR-06-335, McLean, VA, January 11, 2007, p. 1, http://www.fas.org/irp/agency/dod/jason/pit.pdf.

[9] Arnie Heller, "Plutonium at 150 Years: Going Strong and Aging Gracefully," *Science & Technology Review*, December 2012, pp. 12, 14, https://str.llnl.gov/Dec12/pdfs/12.12.2.pdf.

[10] David Clark, "Summary Remarks on Plutonium Aging," LA-UR-13-27541, September 2013, p. 1.

Penrose Albright, then Director of Lawrence Livermore National Laboratory, testified in 2013,

> And there has been a pretty concerted effort at both Los Alamos and at Livermore over the last decade or more that has been looking at plutonium aging, and we actually have samples that we keep in our laboratory—and Los Alamos does the same—that are 40, 50, 60 years old that so far show no—that support the conclusions that the last decade of study has implied, which is that these pits are good for many, many more decades to come.[11]

Longer pit life means that a stockpile of given size can be maintained with a lower pit production rate and opens the possibility of reusing retired pits.

The Pit Production Process

Pits must be made to exacting standards in order to function as designed. This requires precision in fabricating them and in supporting tasks.

As plutonium decays, it produces other elements, such as americium. That radioactive element increases the radiation dose to workers and is an impurity to weapons-grade plutonium. Plutonium scrap, such as from old pits or from faulty castings, may pick up other impurities. Accordingly, plutonium must be purified for use in new pits. This may involve nitric acid processing, high-temperature processing, electrorefining, and other processes.[12] Such processes result in a substantial stream of waste contaminated with radioactive material, acid, and other harmful substances. This waste must be processed and disposed of; waste processing requires a substantial infrastructure.

Pits are fabricated as "hemishells" (half-pits) that are welded together. Rocky Flats Plant made pits using a wrought process, in which sheets of plutonium were run through rollers to attain the desired thickness, then punched into a die. LANL, where pits are currently made, uses a cast process, in which plutonium is melted in crucibles in a foundry, poured into a mold, and finished. The plutonium is analyzed chemically, and each hemishell is inspected through such techniques as physical measurements and x-ray imaging to ensure that there are no flaws. Given the many steps required, it typically takes three months to make a pit.

Various tasks support production. Materials characterization (MC) examines bulk properties of plutonium samples, such as tensile strength, magnetic susceptibility, and surface characteristics. Such properties must be determined to be correct to assure that a pit will, for example, implode symmetrically. MC is generally used to qualify manufacturing processes and to troubleshoot production problems. As such, it does not generate a large number of samples during production, and that number is largely independent of the number of pits to be produced. Of relevance to options considered below, MC does not require a large amount of laboratory floor space.

In contrast, analytical chemistry (AC) is performed across the entire manufacturing process, from metal purification through waste processing.[13] Samples are analyzed for isotopic composition of

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[11] U.S. Congress, Senate Committee on Armed Services, Subcommittee on Strategic Forces, *Hearing to Receive Testimony on National Nuclear Security Administration Management of Its National Security Laboratories in Review of the Defense Authorization Request for Fiscal Year 2014 and the Future Years Defense Program*, 113th Cong., 1st sess., May 7, 2013, committee transcript, p. 14, http://www.armed-services.senate.gov/Transcripts/2013/05%20May/13-36%20-%205-7-13.pdf.

[12] David Clark et al., "Plutonium Processing at Los Alamos," *Actinide Research Quarterly*, 3rd Quarter 2008, pp. 6-16.

[13] Information in this paragraph and the next paragraph was provided by Los Alamos National Laboratory, telephone (continued...)

plutonium and for the type and amount of various impurities. AC is performed on an average of 22 samples per pit. Metal samples taken directly from hemishells are typically 5 grams each. In preparing for AC, these samples are cut into smaller pieces. Most of the smaller pieces are dissolved in acid because most AC instruments do not use samples in solid form. The resulting plutonium-acid mixture is split into still smaller samples, many of which contain milligram or microgram quantities of plutonium. Each sample must be prepared in a specific way, and analyzed using specific equipment, depending on the type of analysis that it is to undergo. In addition, before plutonium ingots are used for a hemishell, their purity must be assayed. This involves taking a sample from a piece of the purified product as well as plutonium standard and reference materials for comparison. In order to provide one assay result for the plutonium, the assay process is typically run ten times.

Pit fabrication generates waste, such as the plutonium-acid samples used in AC, the MC samples, and any shavings or trimmings from finishing hemishells. Accordingly, pit production requires a way to handle the waste. It is treated two ways at Los Alamos; in some cases by extracting plutonium, and in other cases by solidifying it for burial at the Waste Isolation Pilot Plant (WIPP) (NM).

Life Extension Programs

While pits may last for many decades, other weapon components do not. Weapons contain organic components like explosives and adhesives that deteriorate under the influence of heat and radiation given off by plutonium; they may change characteristics over time. Some components, such as electronics, become hard to support after several decades, would be even harder to support several decades from now, and would be difficult to make compatible with new delivery systems like aircraft. Beyond that, some in the National Nuclear Security Administration (NNSA) and DOD want to increase the surety (safety, security, use control, and use denial) of weapons. (NNSA is the semiautonomous DOE agency responsible for nuclear weapons maintenance, several nuclear nonproliferation programs, and all naval nuclear propulsion work.) Accordingly, the Nuclear Weapons Council, a joint DOD-NNSA body that oversees and coordinates nuclear weapon programs, plans a life extension program (LEP) for each weapon type, including some LEPs that may combine two or more weapon types. LEPs range in scope from replacing a few components to a major overhaul that includes new pits, new electronics, and new surety features. Some dispute the need for LEPs that do more than the minimum needed to keep a weapon in service. They argue, for example, that features to further enhance surety are unnecessary given the perfect safety record of U.S. nuclear weapons and that these features add greatly to cost and may impair weapon performance. Nonetheless, LEPs are underway for the W76 warhead for the Trident II submarine-launched ballistic missile and the B61 bomb, and both Congress and the Administration support them. Additional LEPs are being planned.

Pit Production Capacity: How Much Is Needed?

Some LEPs can use the original pit and replace other components, while other LEPs might reuse pits from retired weapons if that proves feasible, and still other LEPs are expected to require fabrication of new pits. U.S. policy, as stated in the Nuclear Posture Review, is specific on its preference among these choices:

(...continued)

conversations, notes, and emails, June-August 2013.

> The United States will study options for ensuring the safety, security, and reliability of nuclear warheads on a case-by-case basis, consistent with the congressionally mandated Stockpile Management Program. The full range of LEP approaches will be considered: refurbishment of existing warheads, reuse of nuclear components from different warheads, and replacement of nuclear components.
>
> In any decision to proceed to engineering development for warhead LEPs, the United States will give strong preference to options for refurbishment or reuse. Replacement of nuclear components would be undertaken only if critical Stockpile Management Program goals could not otherwise be met, and if specifically authorized by the President and approved by Congress.[14]

The need for new "nuclear components," pits in this case, drives pit capacity requirements. However, the pit production capacity considered has varied greatly, from 10 to 450 pits per year. The Nuclear Weapons Council has decided that, to meet the likely demands of future LEPs, a production capacity of 50 to 80 ppy is needed. Andrew Weber, Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, testified in April 2013 that "there is no daylight between the Department of Energy and the Department of Defense on the need for both a near-term pit production capacity of 10 to 20 and then 30 by 2021, and then in the longer term for a pit production capacity of 50 to 80 per year."[15]

While this range of pit production drives the planning for the U.S. plutonium strategy, it is not a precise range based on a careful analysis of military requirements. When asked to explain the basis for this range, Linton Brooks, former Administrator of NNSA, and John Harvey, then Principal Deputy Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, responded:

> MR. HARVEY: We established that requirement back in 2008 for a capability to produce in the range of 50 to 80 per year. That evolved from a decision to basically not take the path that we originally were taking with the Modern Pit Facility, but to go and be able to exploit the existing infrastructure at Los Alamos to meet our pit operational requirements. The capability at Los Alamos was assessed to be somewhere in the range of 50 to 80 per year that they could get with the modernization program they anticipated. The Nuclear Weapons Council looked at that number. It's a capacity-based number, and said it's probably good enough. We'll have to accept some risk, but it's probably good enough.
>
> MR. BROOKS: So you can't tie it to a specific – you can't tie it to a specific deployment schedule or something. It's a judgment that is a combined judgment on yeah, you can probably do this, and yeah in the most reasonable world this will be enough.
>
> MR. MEDALIA: But there's a big difference in the facilities, between 50 and 80. Is it 80 or is it 50 to 80?
>
> MR. HARVEY: We understood that the capability to deliver, based on the anticipated modernization at Los Alamos which would include the CMRR or equivalent, coupled with the PF-4 production, appropriately reconfigured, could deliver in that range. So it was a

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[14] U.S. Department of Defense. *Nuclear Posture Review Report,* April 2010, p. 39.

[15] Testimony of Andrew Weber, Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, in U.S. Congress. Senate. Committee on Armed Services. Subcommittee on Strategic Forces. *Hearing to Receive Testimony on Nuclear Forces and Policies in Review of the Defense Authorization Request for Fiscal Year 2014 and the Future Years Defense Program*, April 17, 2013, p. 15.

> range. I mean, it's always been cited as single shift range. By going to double shifts you could probably get the higher end of that range.
>
> MR. BROOKS: But no person now living can tell you for sure the answer to that question. I mean, you know, beware of spurious precision. … Fifty to 80 is probably as precise as the facts will allow people to be, although people will say other things.[16]

NNSA was also imprecise as to required production capacity. It stated in a 2013 report, "Preliminary plans call for pit production of potentially up to 80 pits per year starting as early as FY 2030. NNSA continues to develop options to achieve a higher production rate as part of the plutonium strategy."[17] John Harvey subsequently added, "The level of 50-80 ppy was consistent with existing PF-4 production capacity plus the analytical chemistry capacity anticipated for the planned CMRR-NF. However, NNSA officials in 2006 believed that a capacity in the range of 125 ppy was needed to respond to anticipated requirements and provide some resilience to surprise. Thus the 50-80 ppy level, while the best that could be done, accepted significant risk in their view."[18]

It may be possible to reduce the capacity required below 80 ppy and still meet DOD's requirements. This might be done in several ways:

- One option under serious study is reusing retired pits in LEPs. Whether this could be done for a particular LEP depends on details of the LEP, whether there are suitable pits available, and whether such pits are available in the quantity required; decisions would have to be made on a case-by-case basis.
- In some LEPs, it may be possible to simply reinstall a weapon's original pit. Neither that method nor reuse of retired pits from other weapons require AC or foundry work. By producing new pits while another LEP is underway with retired or original pits, LANL could use its otherwise-unused capacity to produce pits ahead of schedule for a LEP requiring new pits. Stockpiling new pits would enable lower rates of production and of AC to produce the aggregate number of pits needed by the time they are needed, even if the maximum production rate attainable is less than 80 ppy. In addition, keeping the pit production and support line in continuous operation would be useful if not essential for maintaining processes, equipment, and worker skills, and for training new workers. On the other hand, LEPs require considerable planning and design work, and designs for new pits would have to be certified. In the near term, it might not be possible to do this work far enough in advance to permit continuous production.
- Since the figure of 80 ppy was based on LANL's presumed pit production capacity using PF-4 and CMRR-NF (an existing building and one that has been

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[16] Reserve Officers Association, Air Force Association and National Defense Industrial Association Capitol Hill Breakfast Forum with Linton Brooks, Senior Adviser at the Center for Strategic and International Studies; and John Harvey, Principal Deputy Assistant Secretary of Defense for Nuclear, Chemical and Biological Defense Programs, on "The Nuclear Infrastructure Challenge And Deterrence Implications," June 13, 2013, http://secure.afa.org/HBS/transcripts/2013/June%2013%20-%20Brooks.pdf. CMRR refers to the Chemistry and Metallurgy Research Replacement Nuclear Facility, which has been deferred for at least five years, and PF-4 is the building in which pits are currently manufactured; see ""Existing Buildings at Los Alamos for Plutonium Work."

[17] U.S. Department of Energy. National Nuclear Security Administration. *Fiscal Year 2014 Stockpile Stewardship and Management Plan,* Report to Congress, June 2013, page 2-22.

[18] Personal communication, January 19, 2014.

> deferred for at least five years), not on a strategic analysis of military needs, and since the range cited is 50 to 80 ppy, a capacity of less than 80 ppy might suffice.

The Union of Concerned Scientists stated regarding required pit production capacity:

> If pits last 150 years or more, there is no need to replace aging pits for the foreseeable future, and no rationale for expanding production capacity beyond the existing 10 to 20 annually for this purpose. Even if the NNSA finds that pits will last only 100 years and that all need to be replaced by 2089, production capacity of 50 per year would be adequate.
>
> The NNSA could replace all existing pits by 2089 if it started doing so in 2019, based on the agency's conservative assumption that the U.S. stockpile will remain at 3,500 warheads. However, the United States is likely to reduce its arsenal in coming decades. In that case, the NNSA could either wait longer to begin producing replacement pits … or reduce the annual rate of production. …
>
> Thus, even under the most conservative assumptions about pit lifetime and arsenal size, there is no need to expand pit production capacity beyond 50 per year to replace aging pits. Because both pit lifetime and the future size of the arsenal are uncertain, it makes no sense to expand production capacity until it is needed.[19]

In contrast, John Harvey argues that there is risk in not providing margin to accommodate unknowns:

> Required pit production capacity cannot be based solely on known LEP requirements. We must consider the possibly of surprise: either technical problems in the stockpile that arise unexpectedly or geopolitical reversals. For example, we cannot anticipate at this point a need to increase stockpile size based on renewed threats, but we should not rule out that possibility in setting our pit production needs. Some reserve production capacity is required above and beyond known LEP needs to ensure we have some ability to respond to surprise.
>
> This is entirely consistent with the President's NPR [Nuclear Posture Review] vision for a responsive nuclear infrastructure. The longer we wait on achieving needed capacity, the greater the risk we are accepting in not having responsive capabilities.[20]

It could be argued that an ability to meet the higher requirement—the most challenging case—would enable the United States to meet lower requirements and would put this nation in a better position to meet higher requirements should that be deemed necessary. Further, if 80 ppy proves unattainable, an effort to reach that goal might increase the likelihood that this nation could reach 50 ppy, the lower end of the range.

On the other hand, it could be argued that it is not desirable to have a goal of 80 ppy if that is excess to needs. According to Greg Mello, Executive Director of Los Alamos Study Group,

> It is not clear that efforts to reach a larger pit production capacity will enable lesser pit production capacities. History shows that efforts to acquire pit production capacity above that which is clearly needed, have failed. Facilities to support a larger-than-needed pit production capacity cost more for construction and operation than smaller facilities, and are

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[19] Lisbeth Gronlund et al., *Making Smart Security Choices: The Future of the U.S. Nuclear Weapons Complex,* Union of Concerned Scientists, October 2012, p. 12, http://www.ucsusa.org/assets/documents/nwgs/nuclear-weapons-complex-report.pdf.

[20] Personal communication, January 19, 2014.

> more likely to encounter political objections. So trying for 80 pits per year may decrease the probability of successfully acquiring 50 pits per year, and trying for 50 pits per year may decrease the probability of achieving 30 pits per year. It may be far better to acquire the minimum necessary pit production capacity, and include a contingency plan that can be activated should conditions warrant.[21]

Because of concern over required pit production capacity, Section 3147 of the FY2013 National Defense Authorization Act, P.L. 112-239, directed the Secretary of Defense, in coordination with the Secretary of Energy and the Commander of the U.S. Strategic Command, to "assess the annual plutonium pit production requirement needed to sustain a safe, secure, and reliable nuclear weapon arsenal." The accompanying Joint Explanatory Statement of the Committee of Conference states that the assessment shall include "an assessment of cost and national security implications for various smaller and larger pit production rates from the current 50-80 pit requirement. The conferees note that rates including 10 to 20 pits per year, 20 to 30 pits per year, 30 to 50 pits per year, 50 to 80 pits per year, and larger should be included as part of the analysis."[22] Note that reducing required capacity would reduce facility requirements and might permit delaying facility construction.

The purpose of this report, however, is not to address contending arguments on the capacity needed, but to discuss options for acquiring the maximum capacity DOD states that it needs, 80 ppy, by 2030. Even if in 16 years it turns out that a lower capacity would suffice, it is difficult at best to know that so far in advance.

The difference between 50 and 80 ppy has consequences. As discussed above, the Nuclear Weapons Council reasoned that a capacity to build 50 ppy in single-shift operations could be scaled up to produce 80 ppy in double-shift operations, i.e., double-shift operations can produce 1.6 times as many pits as single-shift operations. But if the actual need is 50 ppy, then by using the same ratio, a capacity to build approximately 30 ppy in single-shift operations could be scaled up to 50 ppy by using two shifts. Deploying and operating a smaller capacity would be less costly and easier to implement.

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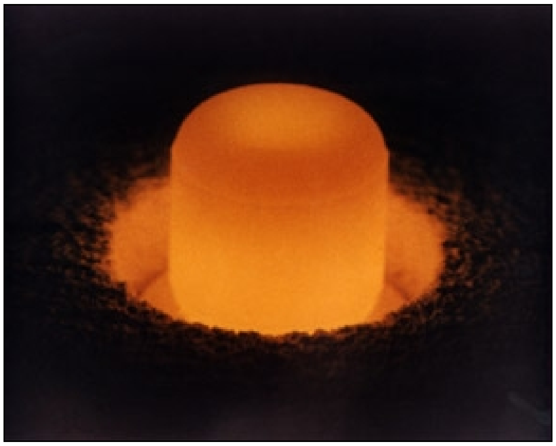
[21] Personal communication, December 16, 2013.

[22] U.S. Congress. House. Committee on Armed Services. *National Defense Authorization Act for Fiscal Year 2013.* Conference report to accompany H.R. 4310. 112th Congress, 2nd Session, H.Rept. 112-705, December 18, 2012, p. 991.

Plutonium-238

Figure 2. Plutonium-238



Source: U.S. Department of Energy,

Note: This figure shows a Pu-238 source glowing under its own light.

Pu-238 is an isotope of plutonium. While it is not used in pits, it figures prominently in several pit production options presented later in this report. It has very different properties and applications than Pu-239. Pu-238 has a much shorter half-life than Pu-239 (87.7 years vs. 24,110 years), so is 275 times more radioactive. Because of its intense radioactivity, it is so hot that a lump of it glows, as **Figure 2** shows. This radioactivity makes it useful in applications requiring a long-lived power source. It is used to provide heat to generate electricity for deep space probes and for defense purposes. At the same time, according to Los Alamos,

> Pu-238 is not desirable for using in pits because it has a relatively short half-life (87.7 years) and the associated decay generates large amounts of heat in the material. Pu-238 is listed in the [DOE] Safeguards Table (DOE 474.2) as attractiveness level D (Low-Grade Materials) because its half-life and associated properties would make it extremely difficult to fabricate into a pit, handle, and may cause problems for surrounding materials [in a nuclear weapon] such as electronics, plastics, etc.[23]

Key Regulatory Terms

Statutes, regulations, DOE orders, etc., as described in **Appendix A**, use many terms. While they are often technical and complicated, understanding several of them is essential for understanding facilities, presented next, and options. Selected terms are presented here; they provide a basis for discussing constraints on plutonium buildings, various ways to comply with these constraints, and how the constraints might be modified.

Dose: The amount of ionizing radiation a person receives, measured in rem.

Rem: This is a unit of measure of the biological effects of all types of ionizing radiation on people. One expert lists a dose of between 0 and 25 rem as having "no detectable clinical effects; small increase in risk of delayed cancer and genetic effects," a dose of 25 to 100 rem as "serious effects on average individual highly improbable," and for 100-200 rem "minimal symptoms; nausea and fatigue with possible vomiting."[24] Note that cancer risks in exposed populations generally increase with dose and number of people exposed.

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[23] Information provided by Los Alamos National Laboratory, email, November 4, 2013.

[24] Dade Moeller, *Environmental Health,* revised edition, Cambridge, Harvard University Press, 1997, p. 250. There is debate on the biological effects of very low levels of radiation. See CRS Report R41890, *"Dirty Bombs": Technical Background, Attack Prevention and Response, Issues for Congress*, by Jonathan E. Medalia, Appendix A, Technical Background; and Dr. Y, "Once More into the Breach," November 5, 2013, which contains links to various documents in the debate, http://blogs.fas.org/sciencewonk/2013/11/breach/.

Plutonium-239 equivalent: Weapons-grade plutonium (WGPu) consists mainly of Pu-239 but includes small quantities of other plutonium isotopes. Some are much more radioactive than Pu-239, and there are many other radioactive substances. It is convenient to convert all radioactive materials to a single standard for purposes of assessing the radiological hazard from a building in the event of an accident. That standard is "plutonium-239 equivalent," abbreviated as Pu-239E in this report. Because WGPu is more radioactive than pure Pu-239, 1 gram (g) of WGPu has the radioactivity of 1.49 g of Pu-239. Similarly, Pu-238 is very much more radioactive than Pu-239; 1 g of Pu-238 has the radioactivity of 275 g of Pu-239.

Hazard Categories (HCs) and Radiological Facilities: Nuclear facilities are categorized in several ways. One is by the hazard they could pose in the event of a major accident. HCs are based on "the consequences of unmitigated releases of hazardous radioactive and chemical material."[25] 10 CFR 830, "Nuclear Safety Management," Appendix A, "General Statement of Safety Basis Policy," divides these consequences into three categories; **Table 1** also includes a related category.

Table 1. Hazard Categories and Radiological Facilities

As Applicable to Plutonium

Hazard Category (HC)	Pu-239 Equivalent (g) a building of this Hazard Category is designed to hold	Description in 10 CFR 830	Comment
1	N/A	Potential for "significant off-site consequences"	Applies to nuclear reactors, not applicable to pits
2	≥2,610 g	Potential for "significant on-site consequences beyond localized consequences"	
3	Less than HC-2, but >38.6 g	Potential for "only local significant consequences"	
Radiological Facility	Less than HC-3		Not part of the Hazard Category System

Source: Hazard Categories are based on an NNSA document, "Guidance on Using Release Fraction and Modern Dosimetric Information Consistently with DOE STD 1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports, Change Notice No. 1,"* Supplemental Guidance, NA-1 SD G 1027, November 28, 2011, http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/NNSA_Supp_Guide_1027.pdf. DOE STD 1027-92, Establishing Hazard Categories is required by 10 CFR 830 (Nuclear Safety Management), Subpart B (Safety Basis Requirements), Section 202(b)(3), http://www.gpo.gov/fdsys/pkg/CFR-2011-title10-vol4/pdf/CFR-2011-title10-vol4-part830.pdf.

Notes: See **Appendix C** for additional details.

Hazard Categories are determined by the amount of Pu-239E a building is designed to hold; each category has the potential for certain consequences in the event of a major accident. 10 CFR 830, Appendix A, states that "the hazard categorization must be based on an inventory of all radioactive materials within a nuclear facility." The HC structure builds in a conservative feature: "The final categorization is based on an 'unmitigated release' of available hazardous material. For the purposes of hazard categorization, 'unmitigated' is meant to consider material quantity, form,

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[25] National Nuclear Security Administration, "Main Points of Draft Supplemental Directive: Alternative Hazard Categorization Methodology for Compliance with 10 CFR 830, Nuclear Safety Management, Safety Basis Requirements," Rev. 0, 3/15/2010, p. 10.

location, dispersibility and interaction with available energy sources, but not to consider safety features (e.g., ventilation system, fire suppression, etc.) which will prevent or mitigate a release."[26] Hazard Categories apply to the design and construction of a building, not to its operation. For example, a building intended to hold 5,000 g of Pu-239E must be designed to HC-2 standards, while a building intended to hold 1,000 g of Pu-239E must be designed to HC-3 standards, which are less stringent.

Closely related, and central to some options discussed later in this report, is the category "Radiological Facility." A Radiological Facility holds less Pu-239E than an HC-3 building. It is not part of the HC system because the amount of material is so small as to pose little threat; a hospital, for example, might be a Radiological Facility. The Radiological Laboratory/Utility/Office Building (RLUOB) figures in several options below and is discussed in "Existing Buildings at Los Alamos for Plutonium Work." As a Radiological Facility, HC standards limit it to 38.6 g of Pu-239E, or 26 g of WGPu, far less than enough to perform the AC needed to support production of 80 ppy.

Design Basis Earthquake (DBE): The DBE is used to set standards for the resilience to earthquakes that buildings in various HCs must have. LANL provided the following information:

> The design basis earthquake is defined as the ground motion that has an annual frequency of 4×10^{-4} or [once in] 2,500 years. This is the ground motion that structures, systems, and components (SSCs) are designed for using national consensus codes and standards. This approach would lead to a failure probability of the SSCs for loads associated with the design basis ground motion of 1-2%. Using this approach it is also expected that at ground motion associated with an annual frequency of 1×10^{-4}, or [once in] 10,000 years, the failure probability of the SSCs would be about 50%.[27]

Design Basis Accident (DBA): This is the accident scenario against which a nuclear facility must be designed and evaluated. Each HC building is required to be built to survive a DBA, the worst-case accident that could plausibly affect the building. Because each building will face different threats, the DBA is necessarily building-specific. For one building, the DBA might be a flood; for another, an explosion of a nearby gas main; for a third, a tornado; and for a fourth, an earthquake. For the plutonium buildings at Los Alamos, described next, the main threat is an earthquake, so the DBA involves (1) an earthquake more powerful than the DBE that (2) collapses a building and (3) starts a fire that involves all material at risk in the facility and (4) releases a certain fraction of the plutonium into the air as plutonium oxide particles. The fraction, in turn, is based on (1) the Airborne Release Fraction (ARF), the fraction of the MAR that the postulated fire could release into the air; (2) the Leak Path Factor (LPF), the fraction of ARF that actually escapes from the building into the air; some of it would be trapped, such as by the collapse of the building; and (3) the Respirable Fraction (RF), the fraction of the plutonium oxide particles released into the atmosphere that are of a size (3 microns or less) that could readily be inhaled and lodge in the lungs, where they would cause biological damage and, quite possibly, lung cancers; larger particles would fall to the ground or would be trapped in the nose. Other variables enter as well; **Appendix B** discusses them in detail.

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[26] U.S. Department of Energy. National Nuclear Security Administration. "Guidance on Using Release Fraction and Modern Dosimetric Information Consistently with DOE STD 1027-92, *Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports, Change Notice No. 1,*" Supplemental Guidance, NA-1 SD G 1027, November 28, 2011, Attachment 1, page 1-2.

[27] Information provided by Los Alamos National Laboratory, email, August 8, 2013.

The frequency of the DBA is much less than the frequency of the DBE because several steps must occur for the DBE to result in the DBA. NNSA commented on this difference:

> There is also margin in the assumed accident frequencies (e.g., once in 5,000 years); these were based on the structural failure probabilities and did not consider other conditional probabilities, such as the conditional probability of a large fire starting and growing within the facility and progressively effecting and engaging all of the assumed material at risk; this refinement would reduce the frequency of the event from once in thousands of years to once in hundreds of thousands of years.[28]

The difference between DBE and DBA is crucial because the path from the one to the other can be interrupted at many places and in many ways in order to reduce the probability of the DBA, as discussed in "Increasing Safety," below.

Radiological Facilities like RLUOB do not have a DBA and do not have to be designed to survive a DBA because they have so little radioactive material, though, as discussed in **Appendix E**, RLUOB was built (but not certified) to HC-3 standards. If RLUOB were to be converted to an HC-3 building, it would need a DBA and might need structural and other upgrades to be able to survive it. **Appendix D** describes some of the tasks needed to convert RLUOB to HC-3.

Material At Risk (MAR): DOE defines this term as "the amount of radioactive materials (in grams or curies of activity for each radionuclide) available to be acted on by a given physical stress."[29] For purposes of this report, it is a measure of the amount of plutonium that might be dispersed in a DBA. Molten plutonium or plutonium shavings in a crucible that topples over in an earthquake, spilling plutonium onto the floor, would be MAR because a fire would create plutonium oxide particles, while plutonium in specially-designed containers that are fire-resistant and rugged enough to survive a building collapse would not face this risk and thus would not be counted as MAR.

Maximally-exposed Offsite Individual (MOI) and other exposure standards: An MOI is a hypothetical person located at the spot—outside the site boundary but nearest to a specific building—where a member of the public could reasonably be, such as a dwelling or a public road. The guideline set by DOE is that the MOI should receive a dose of no more than 25 rem for an exposure of 2 hours (or up to 8 hours in certain situations). "The value of 25 rem TEDE [total effective dose equivalent] is not considered an acceptable public exposure either. It is, however, generally accepted as a value indicative of no significant health effects (i.e., low risk of latent health effects and virtually no risk of prompt health effects)."[30] To avoid "challenging" the 25-rem dose, another DOE document sets the dose at 5 rem, and sets a guideline of 100 rem TEDE for nearby ("collocated") workers.[31]

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[28] Letter from Donald Cook, Deputy Administrator for Defense Programs, National Nuclear Security Administration, to Peter Winokur, Chairman, Defense Nuclear Facilities Safety Board, January 30, 2012, Enclosure 1, pp. 3-4, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Letters/2012/ltr_2012130_18446_0.pdf.

[29] U.S. Department of Energy. DOE Handbook: *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities,* Volume I - Analysis of Experimental Data, DOE-HDBK-3010-94, December 1994, p. xix, http://www.orau.gov/ddsc/dose/doehandbook.pdf.

[30] U.S. Department of Energy. DOE-STD-3009-94, July 1994, Change Notice No. 3, March 2006, "DOE Standard: Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses," Appendix A, "Evaluation Guideline," p. A-2, http://www.hss.doe.gov/enforce/docs/std/DOE_STD_3009.pdf.

[31] U.S. Department of Energy, *DOE Standard: Integration of Safety into the Design Process*, DOE-STD-1189-2008, March 2008, pp. A-5, A-6.

Documented Safety Analysis (DSA): Once an HC-2 or HC-3 building is built, a DSA must be prepared for it. A DSA is an agreement on how much MAR it can contain in order to stay within the dose limits for a collocated worker (for an HC-3 building) or an MOI (for an HC-2 building). The DSA MAR limit is typically less than the upper bound for an HC-3 building; for an HC-2 building, the DSA MAR limit is a specific figure because HC-2 sets no upper bound. For two HC-2 buildings at LANL, CMR and PF-4, discussed below, the agreement is between NNSA and Los Alamos National Security, LLC, the site contractor. The MAR permitted is building-specific based on hazard analysis, including accident scenarios, and on multiple measures designed to contain radioactive material in an accident. For CMR, the MAR permitted by the DSA is 9 kg of Pu-239E; for the main floor of PF-4, the comparable figure is 2,600 kg.[32] A DOE document provides detailed standards for preparing a DSA.[33] No DSA is required for a Radiological Facility because MAR is so small that such facilities fall outside the Hazard Category system.

Security Category (SC): DOE places uranium and plutonium into SCs depending on their attractiveness level, such as to terrorists. SC I and II pertain to facilities with Special Nuclear Materials (SNM, mainly uranium highly enriched in the isotope 235 and plutonium) in quantities or forms that would pose a severe threat if seized by terrorists. The highest level, SC-I, includes assembled weapons and 2 kg or more of plutonium ingots. SC I and II require armed guards, a special security fence, and similar measures. SC-IV requires much less security. It includes less than 200 g of metallic plutonium and less than 3 kg of solutions of less than 25 g of plutonium per liter. **Table C-1** shows amounts of plutonium in various hazard and security categories.

Safety Class, Safety Significant: 10 CFR 830.3 defines safety class structures, systems, and components (SSCs) as SSCs, "including portions of process systems, whose preventive and mitigative function is necessary to limit radioactive hazardous material exposure to the public, as determined from the safety analyses." In contrast, safety significant SSCs "are not designated as safety class structures, systems, and components, but whose preventive or mitigative function is a major contributor to defense in depth and/or worker safety as determined from safety analyses." LANL added this explanation: "Safety-class systems must operate in conditions that otherwise would result in an unacceptable risk (dose) to the public. Relative to the public, safety-significant systems support safety-class systems with additional protections that might help in an accident, but are not counted upon to do so."[34]

Facility Aspects: Buildings to Support Pit Production

Existing Buildings at Los Alamos for Plutonium Work

The nuclear weapons complex (the "Complex") consists of eight sites that maintain U.S. nuclear weapons; during the Cold War, the Complex designed, developed, tested, and manufactured these weapons. The Department of Energy (DOE) and its predecessor agencies used to own and set policy for the Complex. Beginning in 2000, the National Nuclear Security Administration (NNSA), a semiautonomous agency within DOE, took over these functions. Contractors operate Complex sites at the direction of NNSA. One of these sites, Los Alamos National Laboratory (LANL), has three buildings relevant to pits:

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[32] Information provided by Los Alamos National Laboratory, email, November 4, 2013.

[33] U.S. Department of Energy. DOE-STD-3009-94, July 1994, Change Notice No. 3, March 2006, "DOE Standard: Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses."

[34] Information provided by Los Alamos National Laboratory, email, January 22, 2014.

Chemistry and Metallurgy Research (CMR) Building

This building was designed beginning in the late 1940s; most of it was completed by 1952, with another part completed in the early 1960s. It was used mainly for plutonium R&D, and at present provides AC and some MC to support pit production and all other plutonium missions in PF-4.

CMR is showing signs of age. In 2009, a congressional commission found that it and a uranium processing building at the Y-12 National Security Complex are “genuinely decrepit and are maintained in a safe and secure manner only at high cost.”[35] In 2010, the staff of the Defense Nuclear Facilities Safety Board (DNFSB), which monitors safety and health issues at the nuclear weapons complex, “questioned CMR’s ability to detect promptly ventilation system failure, a particularly important function given the system’s age and lack of local alarms to notify facility workers.”[36] In a 2010 report to Congress, DNFSB stated that CMR and Y-12 uranium processing facilities “are structurally unsound and are unsuitable for protracted use.”[37]

Figure 3. Chemistry and Metallurgy Research Building

Source: Los Alamos National Laboratory.

CMR suffers from another problem. As Los Alamos is on several seismic faults, earthquakes pose the greatest threat to CMR. It is not seismically robust. Its design, in the late 1940s, gave little consideration to seismic loads. Further, when it was constructed, there was a steel shortage due to a steel strike and the Korean War. To save on steel, each concrete beam in CMR is reinforced with only two steel reinforcing rods, which are of different diameters, while the concrete floor between the beams is 2 to 4 inches thick, reinforced with chicken wire. A Los Alamos seismic expert calculates that, for CMR, “the annual probability of failure [i.e., building collapse, is] somewhere between 1 in 370 years and 1 in 333 years.” This means that for ground motion that might be associated with an earthquake that may occur approximately every 250 years, there is a 50% probability of collapse. This expert also calculates that the probability that CMR would survive a Design Basis Earthquake, in this case one occurring once in 2,500 years, is less than 0.2 percent.[38] Another calculation using these data is that CMR has a 1 in 36 chance of collapsing in 10 years. DNFSB arrived at a similar calculation:

> *Seismic fragility of building:* There is a 1 in 55 chance of seismic collapse during a 10-year timeframe, which would result in release of nuclear material and injury/death of facility workers.

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[35] William Perry et al., *America’s Strategic Posture*, Congressional Commission on the Strategic Posture of the United States, Washington, United States Institute for Peace Press, 2009, p. 50.

[36] Defense Nuclear Facilities Safety Board, Staff Issue Report, “Chemistry and Metallurgy Research Facility Documented Safety Analysis,” memorandum from C. Shuffler to T.J. Dwyer, Technical Director, September 1, 2010, pp. 4-5, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Staff%20Issue%20Reports/Los%20Alamos%20National%20Laboratory/2010/sir_2010127_4969_65.pdf.

[37] Defense Nuclear Facilities Safety Board, “Summary of Significant Safety-Related Infrastructure Issues at Operating Defense Nuclear Facilities,” letter report to the Congress, September 10, 2010, p. 1, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Reports%20to%20Congress/2010/sr_2010910_4673.pdf.

[38] Emails, September 17, September 27, and October 1, 2, and 10, 2013.

> The Board is concerned that prolonged operations in the existing CMR facility pose a serious safety risk to workers. In late 2010, the NNSA limited material-at-risk in the facility to reduce the public dose consequence following an earthquake to a value below the Evaluation Guideline of 25 rem.[39]

PF-4 (Plutonium Facility 4)

Figure 4. PF-4 and TA-55

Source: Los Alamos National Laboratory.

Notes: Technical Area 55 (TA-55) is the main area at Los Alamos National Laboratory for plutonium work, such as pit manufacturing, R&D, stabilizing of waste for disposition, and nuclear forensics. The photo shows most of TA-55. TA-55 includes PF-4, RLUOB, and the site for the proposed CMRR-NF.

PF-4 is the nation's main building for plutonium work. It manufactures pits and supports many other plutonium projects. It produces Pu-238 heat sources for deep space probes and defense purposes. It houses the Advanced Recovery and Integrated Extraction System (ARIES), which converts the plutonium in pits into plutonium oxide for use in mixed oxide nuclear reactor fuel.[40] It is the venue for pit surveillance, in which pits from deployed weapons are returned to Los Alamos for detailed inspection to search for actual or potential problems. It used to recover americium, a decay product of plutonium, for use in smoke detectors and industrial gauges, and is reestablishing that capability. It conducts plutonium R&D.

DNFSB expressed concern about PF-4's vulnerability to an earthquake:

> PF-4 was designed and constructed in the 1970s and lacks the structural ductility and redundancy required by today's building codes and standards. In 2007, a DOE-required periodic reanalysis of the seismic threat present at the Los Alamos site was completed. It indicated a greater than fourfold increase in the predicted earthquake ground motion. Total facility collapse is now considered a credible event. … In response to this increased seismic threat, LANL undertook a series of actions to improve the safety posture of PF-4.[41]

Radiological Laboratory/ Utility/Office Building (RLUOB)

Design of this building was completed in 2006. The building was completed in FY2010,[42] office operations began in October 2011, and laboratory operations are expected to start in 2014.[43] As a

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[39] U.S. Defense Nuclear Facilities Safety Board. "Summary of Significant Safety-Related Aging Infrastructure Issues at Operating Defense Nuclear Facilities." Fourth Annual Report to Congress, Enclosure, p. E-2, emphasis in original; http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Reports%20to%20Congress/2013/ar_20131030_23051.pdf.

[40] For further information on ARIES, see "Aries Turns Ten," full issue of *Actinide Research Quarterly,* Quarters 1 and 2, 2008, http://arq.lanl.gov/source/orgs/nmt/nmtdo/AQarchive/1st_2ndQuarter08/.

[41] Defense Nuclear Facilities Safety Board, "Summary of Significant Safety-Related Infrastructure Issues at Operating Defense Nuclear Facilities," letter report to the Congress, September 10, 2010, p. 1, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Reports%20to%20Congress/2010/sr_2010910_4673.pdf

[42] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2014 Congressional Budget Request,* DOE/CF-0084, April 2013, Volume 1, National Nuclear Security Administration, p. WA-267.

Radiological Facility, it is permitted to hold 26 grams (g) of WGPu. It has 19,500 square feet (sf) of laboratory space, as compared to 22,500 sf of lab space planned for the Chemistry and Metallurgy Research Replacement Nuclear Facility (CMRR-NF), a building planned but not built, as described in "A Sisyphean History: Failed Efforts to Construct a Building to Restore Pit Production," below. RLUOB (pronounced "rulob") was intended to conduct unclassified R&D on plutonium and some AC in support of pit production; the latter amount was to be very small because CMRR-NF was intended for that purpose. Nonetheless, the design of RLUOB is suitable for AC because it uses open hoods instead of gloveboxes as in PF-4;[44] hoods are more efficient for most AC because it is much easier to work with small samples in them, but they require a powerful ventilation system, which RLUOB has, as shown in **Figure 6**. Indeed, a LANL report stated that "RLUOB has effectively perfect alignment with analytical chemistry activities."[45]

Figure 5. Radiological Laboratory/ Utility/Office Building

Source: Los Alamos National Laboratory.

While RLUOB was intended to be a Radiological Facility, it was constructed to a much higher standard than was required:

> RLUOB was built as a "radiological-plus" or robust radiological facility. The engineering controls associated with worker radiation protection are on par with those inside of PF-4 and well in excess of those in the 1950s-era CMR Building. Additionally, the RLUOB uses modern HEPA filtration, which protects the environment from a release of contamination, and contains a state-of-the-art operations center for managing facility operations including ventilation. In an overarching sense, the RLUOB was built with a focus on the Nuclear Quality Assurance (NQA)-1 standard, which technically is only required for hazard category 3 facilities, but was constructed as such to provide lessons-learned to aid in constructing the CMRR-NF. However, despite its inherent robustness, the RLUOB does not meet the standards established for either a hazard category 2 or 3 nuclear facility because it was by design intended to work in conjunction with a hazard category 2 nuclear facility (the CMRR-NF).[46]

RLUOB was designed to withstand the design basis earthquake (DBE), in this case an earthquake anticipated to strike RLUOB once in 2,500 years. The force of the DBE was based on seismic calculations made in 1995. Accordingly, it is more resilient to earthquakes than PF-4 was as originally built, since PF-4 was designed to an earlier, less energetic DBE. (Upgrades have

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(...continued)

[43] Information provided by Los Alamos National Laboratory, email, December 11, 2013.

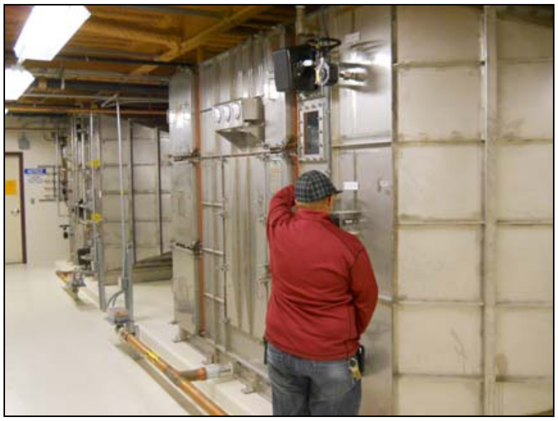
[44] Hoods and gloveboxes are used to manipulate hazardous material, such as acid or plutonium. They contain equipment, such as spectrometers for AC or crucibles for melting plutonium. They have negative air pressure so as to prevent material from escaping into the lab room: air is drawn through the hood or glovebox and then exhausted through a series of filters. A glovebox is a box with a transparent front panel and ports to which heavy gloves are attached. It is supposed to be airtight. An open-front hood is open to the air; laboratory personnel manipulate material using much thinner gloves than is the case for gloveboxes. It is more suitable for handling very small samples or precise adjustment of equipment. Being open, a hood requires much more suction than does a glovebox to keep material from leaking into the room. **Figure 16** shows hoods and gloveboxes.

[45] Brett Kniss and Drew Kornreich, "A Proposal for an Enduring Plutonium Infrastructure," Los Alamos National Laboratory, LA-CP-13-00728 (OUO), June 27, 2013, pp. 22-23. Note: While the report is Official Use Only, this passage has been cleared for unlimited distribution.

[46] Ibid. This passage has been cleared for unlimited distribution.

increased PF-4's resiliency.) As detailed in **Appendix E**, Los Alamos estimates that "collapsing RLUOB would take an earthquake with 4 to 12 times more force than an earthquake that would collapse CMR." However, the current DBE is more energetic than the 1995 DBE; it is unclear what measures, if any, would be needed to strengthen RLUOB to withstand the current DBE.

Figure 6. Air Filters in RLUOB



Source: Los Alamos National Laboratory, October 23, 2013.

Notes: This photo shows a two-stage system in the basement of RLUOB that is used to filter air from the hoods and lab rooms on the laboratory floor. (A separate exhaust system handles air from gloveboxes.) It is essential to maintain "negative pressure" (air pressure lower than that of the room) in the laboratory rooms, hoods, and gloveboxes to prevent fumes and particles from escaping. Multiple exhaust systems are used to maintain negative pressure. Air is drawn from the lab room into the hoods and gloveboxes, then through small HEPA (high-efficiency particulate air) filters in the hoods and gloveboxes; these filters remove at least 99.975% of any particles. The air is then drawn into the ductwork and through large filters in the basement. The system shown here consists of a first stage with pre-filters (over 95% efficiency), which provides cooldown and moisture separation, and a second stage with certified HEPA (at least 99.95% efficiency) filters. This filtered air is exhausted through a stack equipped with a radiation monitor to verify compliance with the Radiation National Emissions Standards for Hazardous Pollutants permitting process. The total air-handling capacity of the hood and glovebox exhaust systems in RLUOB is 32,000 cubic feet per minute.

A Sisyphean History: Failed Efforts to Construct a Building to Restore Pit Production

Beginning in 1952, the United States made pits on a large scale at the Rocky Flats Plant (CO), sometimes over 1,000 ppy. Operations there halted in 1989 as a result of an FBI raid investigating safety and environmental violations. At that point, Rocky Flats was producing pits for the W88 warhead to be carried by Trident II submarine-launched ballistic missiles, but W88 production was not complete. DOE initially considered restarting operations at Rocky Flats, but ultimately decided not to. The United States has not had the capacity to make more than about 10 ppy since 1989.[47]

The history of efforts to restore pit production capacity on a larger scale is voluminous. The key takeaways from the brief summary that follows are: (1) many projects have been proposed over the years; (2) none has been successfully completed; and (3) key parameters, such as cost, schedule, proposed facility site, and capacity, have changed from one proposal to the next.

Complex 21

As the Cold War was winding down, Congress, in Section 3132 of the National Defense Authorization Act for FY1988 and 1989 (P.L. 100-180, December 4, 1987), directed the President to conduct a study on nuclear weapons complex modernization and to "formulate a plan … to modernize the nuclear weapons complex by achieving the necessary

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[47] In 2007, Los Alamos produced 17 pits, but only 11 were "war reserve" pits, i.e., accepted for use in the stockpile. Of the others, some were scrap, and some were used for engineering tests and did not need to be qualified as war reserve. Los Alamos could have made 10 ppy in subsequent years, but there was no DOD requirement for so doing. As a result, in no other year did the total number of pits exceed 10. Information provided by Los Alamos National Laboratory, email, November 12, 2013.

size and capacity determined under the study." The report was submitted in January 1989, but as Secretary of Energy James Watkins noted in January 1991,

> dramatic world changes forced further reassessments of the future Nuclear Weapons Complex." A DOE report resulting from the reassessments "presents a plan to achieve a reconfigured complex, called Complex-21. Complex-21 would be smaller, less diverse, and less expensive to operate than the Complex of today. Complex-21 would be able to safely and reliably support nuclear deterrent stockpile objectives set forth by the President and funded by the Congress.[48]

In addition to a No Action alternative, the study proposed two Reconfiguration alternatives. One would downsize existing sites and modernize them in place. "As an exception to the existing site theme, the functions of the Rocky Flats Plant (RFP) would be relocated." The second, "maximum consolidation," would

> relocate RFP and at least one other NMP&M [Nuclear Materials Production and Manufacturing] facility to a common location. The Pantex Plant and the Oak Ridge Y-12 Plant are candidates for collocation with the Rocky Flats functions, either singly or together. … The probable outcome of this option would be an integrated site which could consolidate much of the NMP&M elements at a single site.

As part of this effort, DOE would develop a Programmatic Environmental Impact Statement "to analyze the consequences of alternative configurations for the Complex," with completion of that statement expected in early FY1994. "Complex-21 should be fully operational early in the 21st century and will sustain the nation's nuclear deterrent until the middle of that century."[49]

What emerged was a two-pronged approach to restore pit production. After conducting an environmental impact statement (EIS) process, DOE issued a Record of Decision (ROD) on Stockpile Stewardship and Management in December 1996 that included reestablishing pit production capability at PF-4 while raising the prospect of a larger-capacity facility.[50] Los Alamos would build a small number of pits for W88s so DOE could replace W88 pits destroyed in an ongoing surveillance program that monitored their condition. Producing these pits, and certifying them as "war reserve," i.e., meeting standards for use in the nuclear stockpile, took many years; PF-4 produced its first war reserve W88 pits, 11 of them, in 2007. This small capacity would also serve as a pilot plant for developing production techniques for a larger plant. Since the total number of additional W88 pits required was small, about 30, there was no need for PF-4 to achieve high manufacturing rates. Producing these pits and certifying them as war reserve without nuclear testing was a major early challenge for the stockpile stewardship program.

Modern Pit Facility

The second prong was to build a facility able to produce large numbers of pits. This was the Modern Pit Facility (MPF). NNSA approved Critical Decision 0 (mission need) for MPF in

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[48] U.S. Department of Energy. *Nuclear Weapons Complex Reconfiguration Study,* DOE/DP-0083, January 1991, cover letter by Secretary of Energy James D. Watkins, Admiral, U.S. Navy (Retired), January 24, 1991.

[49] Ibid., pp. 4-5.

[50] Department of Energy, "Record of Decision: Programmatic Environmental Impact Statement for Stockpile Stewardship and Management," 61 *Federal Register* 68015, December 26, 1996, http://www.gpo.gov/fdsys/pkg/FR-1996-12-26/pdf/96-32759.pdf.

FY2002. The capacity of MPF was left to be decided, for reasons a National Environmental Policy Act (NEPA) document of May 2003 noted:

> Classified studies have examined capacity requirements that would result from a wide range of enduring stockpile sizes and compositions, pit lifetimes, emergency production needs (referred to as "contingency" requirements), and facility full-production start dates. Although the precise future capacity requirements are not known with certainty, enough clarity has been obtained through these ongoing classified studies that the NNSA has identified a range of pit production capacity requirements (125-450 ppy) that form the basis of the capacity evaluations in this EIS. The EIS evaluates the impacts of a MPF designed to produce three capacities: 125 ppy, 250 ppy, and 450 ppy. A pit lifetime range of 45-60 years is assumed.[51]

Congress initially supported MPF, but became increasingly concerned with the lack of study of alternatives, a lack of clarity on the production capacity required, and uncertainty on pit aging and pit life. Finally, Congress eliminated funds for MPF in the FY2006 budget cycle.

Consolidated Nuclear Production Center

Another effort to reconfigure the nuclear weapons complex began in 2004, when the House Appropriations Committee sought to have DOE link the nuclear weapons stockpile with the nuclear weapons complex that would support it:

> During the fiscal year 2005 budget hearings, the Committee pressed the Secretary on the need for a systematic review of requirements for the weapons complex over the next twenty-five years, and the Secretary committed to conducting such a review. The Secretary's report should assess the implications of the President's decisions on the size and composition of the stockpile, the cost and operational impacts of the new Design Basis Threat, and the personnel, facilities, and budgetary resources required to support the smaller stockpile. The report should evaluate opportunities for the consolidation of special nuclear materials, facilities, and operations across the complex to minimize security requirements and the environmental impact of continuing operations.[52]

The Secretary of Energy Advisory Board (SEAB) formed the Nuclear Weapons Complex Infrastructure Task Force to carry out this study. The task force issued its report in July 2005. It recommended immediate design of a Reliable Replacement Warhead (RRW). RRW was a concept in which Cold War aspects of nuclear weapon design, notably maximizing the explosive yield of the weapon per unit weight (the "yield-to-weight ratio"), would be traded off for design features more suitable to the post-Cold War world, such as ease of manufacture, enhanced confidence without nuclear testing, reduced use of hazardous materials, and enhanced surety features.[53] The task force envisioned RRW as a "family of weapons," with RRWs ultimately making up most if not all of the future stockpile. The task force also recommended a Consolidated Nuclear Production Center (CNPC), "a modern set of production facilities with 21st century cutting-edge nuclear component production, manufacturing, and assembly technologies,

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[51] U.S. Department of Energy. *Draft Supplemental Programmatic Environmental Impact Statement on Stockpile Stewardship and Management for a Modern Pit Facility,* DOE/EIS-236-S2, summary volume, May 2003, p. S-27, http://www.energy.gov/sites/prod/files/EIS-0236-S2-DEIS-Summary-2003.pdf.

[52] U.S. Congress, House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 2005*, Report to accompany H.R. 4614, 108th Cong., 2nd sess., June 18, 2004, H.Rept. 108-554 (Washington: GPO, 2004), p. 111, http://www.gpo.gov/fdsys/pkg/CRPT-108hrpt554/pdf/CRPT-108hrpt554.pdf.

[53] For detailed information on the RRW program, see CRS Report RL33748, *Nuclear Warheads: The Reliable Replacement Warhead Program and the Life Extension Program*, by Jonathan E. Medalia.

all at one location … When operational, the CNPC will produce and dismantle all RRW weapons."[54] CNPC would have an SNM manufacturing facility, part of which would support plutonium operations. "All of the functions currently identified in the proposed Modern Pit Facility (MPF) will be located in this building" except for plutonium R&D.[55] CNPC would not manufacture non-nuclear components.[56] Regarding capacity, the report stated:

> A classified Supplement analyzes the issue of timing for the CNPC for a stockpile of 2200 active and 1000 reserve [weapons] and the expected pit manufacturing capacity of the future Complex. The conclusion is that if the NNSA is required to: 1) protect a pit lifetime of 45 years, 2) support the above stockpile numbers, and 3) demonstrate production rates of 125 production pits to the stockpile per year, the CNPC must be functional by 2014. If one accepts the uncertainty of pit lifetime of 60 years, the CNPC can be delayed to 2034. In either case TA-55 is assumed to be producing 50 production pits to the stockpile per year.[57]

Complex 2030

The FY2007 National Defense Authorization Act, P.L. 109-364, directed the Secretary of Energy to develop a plan for transforming the nuclear weapons complex to provide a responsive infrastructure by 2030, and to submit this plan to Congress. The report was submitted in October 2006.[58] The goal was to implement U.S. policy on strategic deterrence as called for in the 2001 Nuclear Posture Review, which recognized the need to transform U.S. nuclear forces from deterring the U.S.S.R. to responding to emerging threats.[59] Regarding the stockpile, NNSA envisioned a smaller stockpile that, by 2030, would be composed mainly if not entirely of RRWs. While the nuclear weapons complex of 2030, "Complex 2030," would continue to have eight sites, quantities of SNM requiring high levels of security would be "only present at production and testing sites."[60] As to labs, in Complex 2030 "No laboratory operations require Category I/II SNM levels of security. Laboratory facilities are not used for nuclear production missions."[61] Unlike the SEAB report, Complex 2030 would not have a Consolidated Nuclear Production Complex but would have "full operations of a consolidated plutonium center at an existing Category I/II SNM site in the early 2020s."[62] Further, "By 2022, LANL will not operate facilities containing CAT I/II quantities of SNM. The location and operator of the consolidated plutonium center will be determined following completion of appropriate National Environmental Policy Act (NEPA) reviews."[63] NNSA would "Plan, construct, and startup a consolidated plutonium center for long-term R&D, surveillance, and manufacturing operations. Plan the consolidated

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[54] U.S. Department of Energy. Secretary of Energy Advisory Board. Nuclear Weapons Complex Infrastructure Task Force. *Recommendations for the Nuclear Weapons Complex of the Future,* final report, July 13, 2005, p. vii, http://www.doeal.gov/SWEIS/DOEDocuments/049%20SEAB%202005.pdf.

[55] Ibid., p. 15.

[56] Ibid., p. 14.

[57] Ibid., p. 17.

[58] U.S. Department of Energy. National Nuclear Security Administration. Office of Defense Programs. *Complex 2030: An Infrastructure Planning Scenario for a Nuclear Weapons Complex Able to Meet the Threats of the 21st Century.* DOE/NA-0013, October 2006, 21 p., http://fissilematerials.org/library/doe06e.pdf.

[59] For an unclassified summary of the review, see U.S. Department of Defense. Nuclear Posture Review Report, 3 p., no date, http://www.defense.gov/news/jan2002/d20020109npr.pdf.

[60] Department of Energy, *Complex 2030,* p. 3. Note that SNM quantities meeting the lower threshold of Category II are different for safety and for security.

[61] Ibid.

[62] Ibid., p. 7.

[63] Ibid., p. 10.

plutonium center for a baseline capacity of 125 units [i.e., pits] per year net to the stockpile by 2022." NNSA would "Upgrade LANL plutonium facilities at Technical Area 55 to support an interim production rate of 30 to 50 RRW war reserve pits per year net to the stockpile by 2012."[64] Regarding another building, NNSA would "Complete and operate the Chemistry and Metallurgy Research Replacement (CMRR) as a CAT I/II facility up to 2022 (use as a CAT III/IV facility and focal point and for material science thereafter) to support plutonium operations at LANL, closure of existing LANL Chemistry and Metallurgy Research (CMR) facility, and the removal of CAT I/II quantities of plutonium from LLNL [Lawrence Livermore National Laboratory]."[65]

Importantly, the plan for Complex 21 shifted capacity from a range of 125 to 450 ppy examined in the MPF EIS to a baseline of 125 ppy.

Chemistry and Metallurgy Research Replacement Project

While nuclear weapons production was at issue, so was R&D on SNM, with a focus at LANL on plutonium. The CMR building had significant problems due to aging and design. As described in a Government Accountability Office report of 2013,

> DOE's and NNSA's plans for replacing the CMR have changed over the past several decades. In 1983, DOE first decided that the CMR was outdated and began making plans to replace it. Over the next nearly 2 decades, several large replacement projects were proposed, but none progressed beyond conceptual stages. … NNSA has taken a number of steps to develop the CMRR nuclear facility or some facility to replace the CMR, but its plans have continued to change over time.[66]

One such project was the Special Nuclear Materials Research and Development Laboratory Replacement Project at LANL. It would have replaced CMR, and would have included a laboratory and facilities for laboratory support, offices, utilities, and waste pretreatment. According to a LANL document of 1990, funding was $10 million for FY1988 and $22 million for FY1989. Anticipated milestones included completion of preliminary design in January 1990, completion of an EIS in 1991, site work start in mid-1991, and construction completed in the fall of 1994.[67]

This project did not happen. Instead, it eventually morphed into the Chemistry and Metallurgy Research Replacement (CMRR) project. In 2002, NNSA reached Critical Decision 0, approve mission need, for the project. In 2003, NNSA completed an environmental impact statement on the project, and in 2004 NNSA issued a Record of Decision (ROD) on it.[68] The preferred option in the ROD included two buildings. The Chemistry and Metallurgy Research Replacement Nuclear Facility (CMRR-NF) was to be a laboratory building that would have provided support, such as AC, for pit production. A separate building, RLUOB, would have provided offices, utilities for both buildings, and laboratory space for R&D. Because the amount of plutonium

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[64] Ibid., p. 11.

[65] Ibid., p. 12.

[66] U.S. Government Accountability Office, *Modernizing the Nuclear Security Enterprise: Observations on NNSA's Options for Meeting Its Plutonium Research Needs*, GAO-13-533, September 2013, p. 8.

[67] Los Alamos National Laboratory, fact sheet: "Special Nuclear Materials Research and Development Laboratory Replacement Project at Los Alamos National Laboratory, LANL-89-48, January 1990, p. 2.

[68] Department of Energy, National Nuclear Security Administration, "Record of Decision: Final Environmental Impact Statement for the Chemistry and Metallurgy Research Building Replacement Project, Los Alamos National Laboratory, Los Alamos, NM," 69 *Federal Register* 6968-6969, February 12, 2004.

RLUOB would have held under then-current regulations was so small, at most 6 grams of WGPu, it was expected to do only a small amount of AC to support weapons production work. In 2005, "NNSA authorized the preliminary design (Critical Decision 1 or CD-1) for the CMRR project."[69] In 2008, NNSA issued an ROD to keep plutonium manufacturing and R&D at Los Alamos and to build CMRR-NF there to support these tasks.[70] RLUOB was completed in FY2010, but CMRR-NF was still in preliminary design at that time.

Congress initially approved the project, but concerns grew as the cost escalated and the schedule slipped. Concurrently, the need to replace CMR became more urgent. Michael Anastasio, then Director of LANL, testified that CMR "is at the end of its useful life," that CMRR "is critical to sustaining the nation's nuclear deterrent" and to other missions, and that "to successfully deliver this project, it will be important to have certainty in funding and consistency of requirements throughout the project."[71] Also, as noted earlier, CMR was "decrepit" and not seismically robust. In an effort to secure Senate approval of the New START Treaty, the Administration issued a report in November 2010 stating that it "is committed to fully fund the construction of the Uranium Processing Facility (UPF) and the Chemistry and Metallurgy Research Replacement (CMRR)" and set out a ten-year funding profile for both facilities.[72] The New START resolution of ratification included provisions related to the nuclear weapons complex in general and to CMRR and UPF in particular.[73] The Administration requested the amount indicated in its November 2010 report in the FY2012 budget. However, in the FY2013 request, the Administration eliminated funding for CMRR-NF and "deferred" it "for at least five years" on grounds that the CMRR facility, UPF, and a life extension project for the B61 bomb were unaffordable concurrently and that there were alternative ways of accomplishing the tasks that CMRR-NF was to perform.[74] However, Section 3114 of the FY2013 National Defense Authorization Act (P.L. 112-239) directed the Secretary of Energy to "construct at Los Alamos National Laboratory, New Mexico, a building to replace the functions of the existing Chemistry and Metallurgy Research Building at Los Alamos National Laboratory associated with

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[69] U.S. Department of Energy. National Nuclear Security Administration. "Chemistry and Metallurgy Research Building Replacement Project," May 2007 p. 3, http://www.doeal.gov/SWEIS/OtherDocuments/427%20NNSA%202007%20CMR%20senate%20report.pdf

[70] National Nuclear Security Administration, "Record of Decision for the Complex Transformation Supplemental Programmatic Environmental Impact Statement—Operations Involving Plutonium, Uranium, and the Assembly and Disassembly of Nuclear Weapons," 73 *Federal Register* 77647, December 19, 2008.

[71] "Prepared Statement of Dr. Michael R. Anastasio, Director, Los Alamos National Laboratory, Los Alamos, NM," in ibid., p. 405.

[72] U.S. White House. *November 2010 Update to the National Defense Authorization Act of FY2010 Section 1251 Report: New START Treaty Framework and Nuclear Force Structure Plans,* pp. 5, 9, http://www.lasg.org/CMRR/Sect1251_update_17Nov2010.pdf. The Uranium Processing Facility at the Y-12 National Security Complex (TN) would replace Y-12's 9212 complex, a uranium processing facility; its first buildings were built during World War II. Note that 9212 is sometimes referred to as a building, and sometimes as a complex.

[73] This resolution, "Treaty with Russia on Measures for Further Reduction and Limitation of Strategic Offensive Arms" (Treaty Doc. 111–5), as agreed to by the Senate, is available at "Treaty with Russia on Measures for Further Reduction and Limitation of Strategic Offensive Arms—continued," *Congressional Record*, December 22, 2010, pp. S10982-S10985, http://www.gpo.gov/fdsys/pkg/CREC-2010-12-22/pdf/CREC-2010-12-22-pt1-PgS10982.pdf#page=1.

[74] U.S. Department of Energy. Office of Chief Financial Officer, *FY 2013 Congressional Budget Request*, Volume 1, National Nuclear Security Administration, DOE/CF-0071, February 2012, p. 185, http://www.mbe.doe.gov/budget/13budget/Content/Volume1.pdf; and Statement of Donald Cook, Deputy Administrator for Defense Programs, National Nuclear Security Administration, in U.S. Congress. Senate. Committee on Armed Services. Subcommittee on Strategic Forces. *Hearing to Receive Testimony on Strategic Forces Programs of the National Nuclear Security Administration and the Department of Energy's Office of Environmental Management in Review of the Department of Energy Budget Request for Fiscal Year 2013,* March 14, 2012, pp. 29-30, http://www.armed-services.senate.gov/Transcripts/2012/03%20March/12-12%20-%203-14-12.pdf.

Department of Energy Hazard Category 2 special nuclear material operations." This provision also barred any funds to be spent on a plutonium strategy for NNSA "that does not include achieving full operational capability of the replacement project by December 31, 2026." However, Congress appropriated no funds for CMRR-NF for FY2013.

For FY2014, the Administration requested no funds for CMRR-NF, and Congress authorized and appropriated no funds for it. However, Section 3117 of the FY2014 National Defense Authorization Act (H.R. 3304, P.L. 113-66) included an exception to the plutonium strategy provision just noted. It authorized NNSA to spend funds on a modular building strategy, i.e., "constructing a series of modular structures, each of which is fully useable, to complement the function of the plutonium facility (PF–4) at Los Alamos National Laboratory, New Mexico, in accordance with all applicable safety and security standards of the Department of Energy." Option 12 describes the modular strategy.

Two Other Failed Attempts

As a further illustration of difficulties in building facilities to handle plutonium, this section presents two facilities that were built, found to be unusable, and demolished.

Nuclear Materials Storage Facility (NMSF): This building was built at LANL. According to the DOE FY1984 budget request, "This project provides for the construction of a repository for long and intermediate storage of large quantities of source and special nuclear materials. It will be designed to meet security, safety, and safeguards requirements for the storage and handling of nuclear materials. The new 29,100-square-foot building will contain a vault area of approximately 13,000 square feet."[75] A 1997 report by the DOE Inspector General was scathing:

> We found that the NMSF, which was originally completed in 1987, was so poorly designed and constructed that it was never usable and that DOE officials were proposing to renovate the entire facility. Departmental and contractor officials discovered numerous design, construction and operational deficiencies after the facility was occupied in February 1987. These deficiencies included: (1) the inability to control and balance the heating, ventilation and air conditioning (HVAC) system to maintain acceptable negative pressures within the facility; (2) the inability to dissipate the heat generated by radioactive decay of the materials to be stored; (3) the inability to limit personnel radiation exposures to "as low as reasonably achievable;" (4) a peeling of the "Placite" decontamination epoxy coating throughout the facility; and (5) the inability to open and secure the Safe Secure Trailer (SST) doors due to the inadequate width of the garage once the SSTs were parked in the garage.[76]

Because of these and other deficiencies, "This structure was never used for storage of nuclear materials, and a decision was made in 2006 to demolish the structure."[77] Demolition was completed by the end of FY2008.[78]

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[75] U.S. Department of Energy. Assistant Secretary for Management and Administration. Office of the Controller. *Congressional Budget Request, FY 1984,* Volume 1: Atomic Energy Defense Activities, DOE/MA-0064/1, January 1983, p. 61

[76] U.S. Department of Energy. Office of Inspector General. *Report on Inspection of Alleged Design and Construction Deficiencies in the Nuclear Materials Storage Facility at the Los Alamos National Laboratory,* report. INS-O-97-01, January 16, 1997, p. 3, http://energy.gov/sites/prod/files/ins-9701.pdf. SSTs are DOE trucks specially outfitted to transport nuclear weapons and related components and materials.

[77] U.S. Department of Energy. National Nuclear Security Administration. Los Alamos Site Office. *Final Site-Wide Environmental Impact Statement for Continued Operation of Los Alamos National Laboratory, Los Alamos, New Mexico,* Volume 3, Comment Response Document, Book 1, DOE/EIS-0380, May 2008, page 1-8, http://www.doe.gov/ (continued...)

Building 371: A press report tells the story of a plutonium project at Rocky Flats:

> One striking example of a construction project that turned out to be a failure was a $225 million plutonium processing building at the Rocky Flats Plant near Golden, Colo. The processing plant, Building 371, was started in 1973, completed in 1981 and operated for a month in 1982 before being shut because the new processing technology did not work. The Energy Department has estimated that it will cost nearly $400 million and take eight years to make the equipment in the building work.
>
> "The fact of the matter is that Building 371 is a fiasco," said Joseph F. Salgado, the Deputy Secretary of Energy. "It's a horror story. It's unacceptable."
>
> Building 371 was intended to replace another, much older processing plant, Building 771. … The Energy Department shut Building 771 on Oct. 8 after three employees were exposed to plutonium dust, which can be extremely dangerous if it is inhaled. The closing of Building 771 was, [sic] the nation's sole source of reprocessed plutonium, which is used in triggers for thermonuclear bombs. The closing has brought most of the plant's operations at the Rocky Flats Plant to a halt.[79]

The building was never put into operation. Instead, the buildings at Rocky Flats Plant, including Building 371, were torn down and the site was decontaminated.[80]

Options for Congress

Analysis of Alternatives

For many years, Congress has been concerned with cost growth and schedule delays in nuclear weapons complex programs for facilities and weapons. One way to help resolve this problem may be to have a thorough airing of alternatives before decisions are made. Most recently, in its work on the FY2014 budget, Congress pressed NNSA to analyze alternatives:

- The Senate Armed Services Committee noted that "NNSA spent about 10 years and more than $350 million on the design of the CMRR Nuclear Facility" before it was deferred and a larger amount on another project that was canceled. The committee stated that "these decisions raise serious questions about how well NNSA scrutinizes the analyses of alternatives prior to submitting them for review and approval." Accordingly, it directed GAO to study, among other things, NNSA's process for analyzing alternatives.[81]

(...continued)

sites/prod/files/EIS-0380-FEIS-03-1-2008.pdf.

[78] Los Alamos National Laboratory, *Fiscal Year 2008 Institutional Commitments—Final Report,* c. late 2008, p. 4.

[79] Keith Schneider, "U.S. Spent Billions on Atom Projects That Have Failed," *New York Times,* December 12, 1988, http://www.nytimes.com/1988/12/12/us/us-spent-billions-on-atom-projects-that-have-failed.html?pagewanted=all&src=pm.

[80] U.S. Department of Energy. Office of Legacy Management. Rocky Flats Site. Colorado, "Fact Sheet," p. 1, available via http://www.lm.doe.gov/land/sites/co/rocky_flats/rocky.htm.

[81] U.S. Congress. Senate. Committee on Armed Services. *National Defense Authorization Act for Fiscal Year 2014.* Report to accompany S. 1197. S.Rept. 113-44, 113th Congress, 1st Session, June 20, 2013, p. 259.

- The House Armed Services Committee, in its report on H.R. 1960, the FY2014 defense authorization bill, stated that Section 3113 would "require the Secretary of Energy, acting through the [NNSA] Administrator, to request an independent review of each guidance issued for the analysis of alternatives for each nuclear weapon system undergoing life extension and each new nuclear facility of the nuclear security enterprise as well as the results of such analysis of alternatives. The Secretary of Energy, acting through the Administrator, would be required to submit the results of any such analysis to the Nuclear Weapons Council and the congressional defense committees." Section 3113 also "would express the sense of Congress that Congress encourages the Administrator and the Nuclear Weapons Council to follow the results of the analysis of alternatives of a life extension program or a defense nuclear facility construction project when selecting a final option."[82] This provision was included in H.R. 1960 as passed by the House. Section 3112 of the FY2014 National Defense Authorization Act (H.R. 3304, P.L. 113-66) contained related language.

- Section 311 of H.R. 2609, the FY2014 energy and water development appropriations bill as passed by the House, directs the Secretary of Energy to submit "a report which provides an analysis of alternatives for each major warhead refurbishment program that reaches [a certain stage]."

- The Senate Appropriations Committee expressed its concern "about NNSA's ability to assess alternatives, which may significantly reduce cost, at the preliminary planning stages of a project." It referred to the deferral of CMRR-NF and the cancellation of another project, each incurring planning costs of hundreds of millions of dollars, and noted, "The Committee believes this wasteful spending could have been avoided had NNSA better assessed alternatives." Accordingly, it directed NNSA to submit a plan on how NNSA "will strengthen its ability to assess alternatives."[83]

- Section 312 of the FY2014 Consolidated Appropriations Act (H.R. 3547, P.L. 113-76) requires the Secretary of Energy to submit to Congress an analysis of alternatives for the B61-12 LEP and certain other major warhead refurbishment programs.

The Role of the National Environmental Protection Act (NEPA) Process in an Analysis of Alternatives

Over the past several decades, many projects, including some in the nuclear weapons complex, have been delayed or stopped by lawsuits brought by nongovernmental organizations under the National Environmental Policy Act (NEPA) of 1969, P.L. 91-140, as amended. These lawsuits typically involve procedural issues of compliance with NEPA in preparing an environmental impact statement (EIS). For example, plaintiffs might charge that an agency filed an inadequate EIS or did not consider all reasonable alternatives adequately.

Secretary of Energy Steven Chu stressed the importance for DOE of complying with NEPA:

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[82] U.S. Congress, House. Committee on Armed Services, *National Defense Authorization Act for Fiscal Year 2014*, Report on H.R. 1960 together with additional and dissenting views, 113th Cong., 1st sess., June 7, 2031, H.Rept. 113-102 (Washington: GPO, 2013), p. 351.

[83] U.S. Congress. Senate. Committee on Appropriations. *Energy and Water Development Appropriations Bill, 2014*. Report to accompany S. 1245. S.Rept. 113-47, 113th Congress, 1st Session, June 27, 2013, p. 100.

> Compliance with the National Environmental Policy Act (NEPA) is a pre-requisite to successful implementation of DOE programs and projects. Moreover, the NEPA process is a valuable planning tool and provides an opportunity to improve the quality of DOE's decisions and build public trust. Hence, timely attention to NEPA compliance is critical to accomplishing our missions. …
>
> I cannot overstate the importance of integrating the NEPA compliance process with program and project management and of applying best management practices to NEPA compliance in DOE," and pointed to the DOE NEPA Order as a "[tool] available to help improve the efficiency of its NEPA compliance efforts.[84]

Several options discussed below involve increasing the amount of plutonium in RLUOB beyond that permitted for a Radiological Facility so it could perform the AC needed to support production of 80 ppy. Section 102 of NEPA would seem to require an EIS for those options because the increase could raise the risk to the "human environment" in a major accident. Section 102 directs all federal agencies to

> (C) include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on—
>
> (i) the environmental impact of the proposed action,
>
> (ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,
>
> (iii) alternatives to the proposed action,
>
> (iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and
>
> (v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented.

In 2008, NNSA prepared a broad ("site-wide") EIS for LANL that included the plutonium program there. Given the state of flux of the plutonium program, NNSA has not prepared an EIS on it since then, though in 2011 it prepared a Supplemental EIS narrowly focused on the CMRR-NF component of the CMRR project.

However, Greg Mello, Executive Director of Los Alamos Study Group, a nongovernmental organization, argues that "an EIS must precede NNSA's choice between post-CMRR-NF plutonium sustainment alternatives." He prepared the following analysis in August 2013 for this report. Since the study group has filed four NEPA lawsuits against Los Alamos construction projects over the past two decades, this analysis merits particular attention. [85]

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[84] "Memorandum for Heads of Departmental Elements," from Steven Chu, Secretary of Energy, subject: "Improved Decision Making through the Integration of Program and Project Management with National Environmental Policy Act Compliance," June 12, 2012, http://energy.gov/sites/prod/files/S-1MemoIntegratingNEPA_with_Program_and_ProjectManagement_2012.pdf. The DOE Order referenced, DOE O 451.1B, "National Environmental Policy Act Compliance Program," Change 3, January 19, 2012, is available at http://energy.gov/sites/prod/files/DOEO4511B_011912.pdf.

[85] For information on its most recent litigation, see Los Alamos Study Group, "CMRR Nuclear Facility: Litigation under the National Environmental Policy Act (NEPA)," updated August 5, 2013, http://www.lasg.org/CMRR/ (continued...)

The main elements of the NEPA landscape are (1) a statute that elevates environmental values to a major purpose of governance, establishes a procedural approach to integrating those values in decisions, and creates a Council on Environmental Quality (CEQ) to oversee this process; (2) CEQ regulations that are binding on agencies; (3) agency regulations, harmonious with CEQ's but tailored to each agency; (4) CEQ guidance that lacks the force of law but is frequently cited by courts; and (5) a body of case law, based on thousands of cases, that creates a sort of NEPA "common law"—some universally binding, some binding in some federal districts, and some influential for such reasons as lucidity. Early NEPA case law established some basic parameters of implementation, such as that citizens could sue agencies to enforce NEPA compliance. Over time, a body of NEPA law has developed that is relatively settled for most basic legal issues but contested in other areas, especially where decisions depend on particular facts.

DOE requires an EIS and a Record of Decision (ROD) as early steps for all major projects that may have significant impacts. In the case of CMRR-NF, a careful EIS that really compared alternatives realistically would have noticed the earthquake-amplifying stratum of volcanic ash beneath the site and incorporated the latest seismic information, problems that later bedeviled the project. The underlying weaknesses in purpose and need could have been vetted as well, and hundreds of millions of dollars in design costs and many years of delay in acquiring safer plutonium capabilities could have been avoided. Sound EISs and formal RODs would strengthen DOE's project management.

I believe that an EIS must precede NNSA's choice between post-CMRR-NF plutonium sustainment alternatives. An EIS requires objective environmental analysis of all reasonable alternatives prior to actions that irreversibly commit federal resources or bias the agency toward an alternative, with an initial business-case analysis used to establish which alternatives are reasonable. Because NNSA has proposed alternatives to CMRR-NF that are major federal actions that could have significant effects on the human environment, and since NNSA has no EIS that analyzes the impact of these alternatives, NNSA must initiate an EIS to do so. Some proposed CMRR-NF alternatives encompass multiple states and sites and may cost billions of dollars. All alternatives will have significant environmental impacts over much of this century.

The relative environmental benignity of upgrading RLUOB to an HC-3 facility might tilt the scales toward that choice but is not a reason not to do an EIS. Upgrading RLUOB may not be the whole of the post-CMRR-NF redirection in plutonium programs. Other nuclear weapons complex sites are under consideration for involvement, including [Lawrence Livermore National Laboratory, Nevada National Security Site, Waste Isolation Pilot Plant], and perhaps [Savannah River Site]. LANL is also considering building "modular" plutonium facilities and is actively briefing this option to Congress. An EIS is definitely required for choices of this magnitude. None of these alternatives, let alone "all reasonable alternatives" as the law requires, have been weighed and their impacts compared in any EIS. Furthermore, NEPA's regulations and case law are clear that an agency cannot analyze one project's alternatives and build something quite different, or take one action today and significantly add to that action later, or do so contemporaneously with separate but connected projects. Congress has been anxious to see a formal plan for plutonium sustainment; the formality of NEPA process would help provide that plan while also serving as a barrier to "scope creep" and associated cost escalation.

It cannot be overemphasized that NEPA's analysis of alternatives serves public purposes beyond environmental ones. As John Immele, former director of LANL's nuclear weapons program, wrote in late 1999 regarding the NEPA process, "A ... lesson from the weapons

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(...continued)

Litigation/CMRR-NF_litigation.html.

> program of the early and mid 1990s as well as the fissile materials disposition program is the necessity for and (surprising) success of publicly vetting our strategies through environmental impact statements."

A thorough EIS analysis of plutonium program alternatives would be a way of complying with NEPA, would be responsive to congressional desires to have NNSA analyze alternatives, would reduce the likelihood that lawsuits filed to challenge the alternative chosen would succeed, and would thus reduce the likelihood that such lawsuits would be filed.

Potential Options

Many options are possible. Ideally, all would meet multiple, and sometimes conflicting, goals, such as:

- Support production of 80 ppy.
- Support all other necessary plutonium work, however "necessary" is defined. Examples might include ARIES, producing plutonium-238 sources, conducting plutonium R&D, and processing liquid waste containing plutonium in order to reduce its volume for shipment to WIPP.
- Reduce safety and security risks (building collapse in an earthquake or other disaster, dose to workers and the public resulting from an accident, terrorist attack leading to detonation of a nuclear device, etc.) to an acceptably low level.
- Maximize cost-effectiveness and ensure affordability.
- Complete the project on a schedule that supports needed work.
- Halt program operations in CMR in approximately 2019.[86]
- Provide a planning margin for the facility to meet, in the future, new or expanded missions or more stringent regulatory requirements.
- Maximize useful life of the facility or facilities.
- Comply with all existing regulations.

Clearly, the more requirements that are levied on a project, the harder it is to comply with them all. In this case, none of the options presented here could meet all these goals simultaneously, and in some cases there is little or no data to evaluate how well an option would meet its goals. Thus Congress is faced with a choice among imperfect options.

The following list includes a broad spectrum of options. The list is presented as a progression, with a logical connection from one option to the next. Each connection is shown in italics.

As a start, consider options using existing buildings at Los Alamos, home to the only U.S. pit manufacturing capability. Since RLUOB is permitted to hold only a few grams of plutonium and CMR is at considerable seismic risk and due to be closed out, why not …

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[86] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2014 Congressional Budget Request,* DOE/CF-0084, April 2013, Volume 1, National Nuclear Security Administration, p. WA-168.

Option 1. Focus PF-4 on Pit Production; Move Other Tasks Elsewhere as Needed

PF-4 has enough lab space, about 60,000 sf, to produce about 10 ppy with RLUOB supporting some low-MAR AC. LANL estimates that PF-4 could be used to manufacture 30 ppy without having to move out any ongoing programs. Attaining this higher capacity would require several actions including reconfiguring existing space and "invest[ing] in new equipment (acquire/install) to increase capacity to 30 pits per year."[87] As a hedge against inadequate plutonium processing capacity, NNSA's Plutonium Metal Processing subprogram would process plutonium alloy from pits returned from Pantex so as to create an inventory of metal for pits before it is needed; doing so "helps ease constraints on Analytical Chemistry (AC) capacity and reduce out-year risk to achieve capacity targets."[88] Both of these activities serve to increase pit-manufacturing capacity without requiring additional laboratory space.

Furthermore, NNSA's plutonium strategy is considering ways to make better use of space in PF-4 and RLUOB to support the transition of AC and MC capabilities from CMR. Some space would be made available for this transition by reclaiming or "repurposing" rooms in PF-4 that are no longer in use (e.g., because the projects they housed have been completed), and some would come from reconfiguration, i.e., rearranging equipment to increase efficiency. The former would add net space for AC/MC; the latter would not. AC equipment also would be added in RLUOB. In total, these actions would affect 8,000 sf in PF-4.[89] A Los Alamos study considered using a facility at Livermore (see Option 7) and RLUOB for AC but did not consider having PF-4 perform all the AC work itself. In part this is because AC is space-intensive and PF-4 would not have sufficient space for production of 30 ppy plus the AC needed to support that capacity.

AC would pose this problem because PF-4 is not configured for a large amount of AC. While some AC operations that use gram quantities of plutonium can be performed in gloveboxes, most AC operations use tiny samples, such as milligram or microgram quantities of plutonium dissolved in acid and placed in very small containers. Manipulating them is much easier in open-front hoods using thin gloves; it would be much harder to manipulate these samples with the multiple layers of gloves required for PF-4 glovebox work. However, hoods require a powerful ventilation system to create negative pressure in the hoods (so no fumes or plutonium escape), and multiple large HEPA filters. Gloveboxes require much less ventilation capacity since any air that flows into them does so through small leaks. PF-4, which is mostly outfitted with gloveboxes, does not have sufficient air handling capacity to support the hoods needed for 30 ppy.[90] It would be difficult to replace gloveboxes with open-front hoods in PF-4 because the PF-4 ventilation system was not configured for the large airflow that hoods require.[91] Upgrading PF-4 ventilation to support the large number of hoods needed to provide high AC capacity would at best be extremely costly. Indeed, the ventilation system to support open-front hoods is so bulky, as shown in **Figure 6**, that it might not be possible to retrofit it into PF-4 at any cost. By

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[87] U.S. Department of Energy. *FY 2014 Congressional Budget Request,* Volume 1, National Nuclear Security Administration, p. WA-64.

[88] Ibid., p. WA-68.

[89] Figure provided by Los Alamos National Laboratory, January 24, 2014.

[90] Information provided by Los Alamos National Laboratory, September 2013.

[91] An open-front hood in normal operations draws 500 cubic feet per minute (cfm) of air, while a glovebox in an accident condition (i.e., with a glove breach) draws about 33 cfm, and a glovebox in normal operations draws very little air. Thus air handling equipment for a hood must have about 15 times the capacity of equipment for gloveboxes. Information provided by Los Alamos National Laboratory, email, October 16, 2013.

extension, even if all of PF-4 were devoted to pit manufacture and supporting tasks, it appears highly improbable that PF-4, by itself, could do all the work needed to produce 80 ppy. There would also be the issue of where to house the tasks that would be moved out.

Given those problems, why not …

Option 2. Build CMRR-NF

Another option is to resume work on CMRR-NF. That building, after all, was not canceled—it was merely "deferred" for "at least five years." Los Alamos estimates that if construction were to begin in FY2018, the building would be completed in 2029, with the five-year delay adding another two years to construction time due to the need to assemble crews, let contracts, etc. Even so, this completion date would be in time for CMRR-NF to contribute to reaching the goal of producing 80 pits per year by 2030. CMRR-NF would provide HC-2 space for AC and MC in support of weapons production. While it is not at all certain that the facility will be built, it could be built if Congress chose to provide funding for it.

This option faces many difficulties. The conditions that led the Administration to defer CMRR-NF in FY2013 remain in place, and in some cases have arguably become more salient since then.

- In deferring CMRR-NF, the Administration argued that building UPF and CMRR-NF and beginning the B61-12 LEP simultaneously would be unaffordable, and that available options would enable the nuclear weapons complex to perform the tasks of CMRR-NF.

- The cost of UPF has increased and its schedule has slipped, possibly necessitating a scaled-back version of UPF.[92] This adds weight to the Administration's judgment about the affordability of CMRR-NF, UPF, and the B61-12 LEP if done simultaneously.

- Section 3114 of the National Defense Authorization Act for FY2013, P.L. 112-239, required the Secretary of Energy to construct, at Los Alamos, "a building to replace the functions of the existing Chemistry and Metallurgy Research Building at Los Alamos National Laboratory associated with Department of Energy Hazard Category 2 special nuclear material operations." However, NNSA requested no funds for CMRR-NF in FY2013 or FY2014, and Congress appropriated no funds for it in those years.

- As detailed in P.L. 113-66, FY2014 National Defense Authorization Act, Section 3117, "Authorization of Modular Building Strategy as an Alternative to the Replacement Project for the Chemistry and Metallurgy Research Building, Los Alamos National Laboratory, New Mexico," Congress is willing to consider modules (see Option 12) as an alternative to CMRR-NF. (Note that modules would perform high-MAR work while CMRR-NF would have performed mainly AC, which involves much less MAR.)

- A modified RLUOB that could "perform the functions of the existing Chemistry and Metallurgy Research Building," as discussed under Options 8-10, would meet most of the functionality requirement of Section 3114 of P.L. 112-239, though not the requirement for

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[92] "A seismic shift on UPF? NNSA to develop alternative scenarios for getting out of 9212, replacing uranium capabilities within 'original cost range,'" Frank Munger's Atomic City Underground (blog), January 15, 2014, http://knoxblogs.com/atomiccity/2014/01/15/shift-upf-nnsa-develop-alternative-scenarios-getting-9212-replacing-uranium-capabilities-within-original-cost-range/#more-11019.

a new building. (It would not provide vault space, as CMRR-NF would have, but it appears that the PF-4 vault will suffice, as discussed in "Options 6-12 Overview: Matching Plutonium Tasks to Buildings.")

- By the time construction could resume on CMRR-NF, other options, such as those the Administration was considering, would presumably be well developed, reducing the added value of CMRR-NF.

- Congress expressed concern over the escalating cost and delays of CMRR-NF, going so far as to impose cost and schedule caps on the project in Section 3114; would Congress be confident that NNSA could bring CMRR-NF online on schedule and on budget?

But even building CMRR-NF would not address the fact that PF-4 would be over 50 years old when CMRR-NF came online, leaving aging and seismic issues unresolved. It may be possible to resolve them with another option …

Option 3. Build a New Building Combining PF-4 and CMRR-NF Functions at LANL

A new building could combine the functions of PF-4 and CMRR-NF. The argument for this option is that PF-4 will be 50 years old in 2028, about when CMRR-NF could be completed. Combining the two buildings into one would presumably cost less than building two separate buildings and would avoid the need to transfer material between buildings, increasing efficiency. A new building would incorporate the most advanced techniques to minimize seismic risk.

This option encounters many difficulties. The building would be larger and more complex than either of the two smaller buildings, and complexity in a major nuclear construction project could be expected to drive up costs and stretch out the schedule. Whereas CMRR-NF design work is nearly completed, the new building would have to be designed from scratch, adding time and cost. Also at issue is the need for this facility. NNSA's TA-55 Reinvestment Project (TRP) plans to extend PF-4's life to approximately 2039,[93] so combining the two buildings would forgo a decade of PF-4 useful life. TRP cannot be halted on the chance that the new building would be built: given the immense difficulties that earlier large facilities have encountered, there is no assurance that the new building would be built. Some key nuclear facilities, notably Building 9212 and CMR, have service lives of over 60 years.[94] RLUOB, too, should have at least a 50-year life, i.e., to 2059, since it was built to much higher standards than CMR or Building 9212. Upgrades could presumably extend its life. If RLUOB and PF-4 together can do the necessary plutonium work for at least another quarter-century, it would seem premature to even start planning a replacement facility now.

Despite advances in design and construction that reduce seismic risk, this building would still be at some risk from an earthquake if sited at Los Alamos. A simple way to avoid this risk is to …

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[93] U.S. Department of Energy. Office of Chief Financial Officer, FY 2014 Congressional Budget Request, Volume 1, National Nuclear Security Administration, DOE/CF-0084, April 2013, p. WA-211.

[94] Building 9212 at Y-12 is a uranium processing facility; "9212" is sometimes referred to as a building, and sometimes as a complex with its first buildings built during World War II.

Option 4. Build a Building Combining PF-4 and CMRR-NF Functions at Another Site

Constructing this building at a nuclear weapons complex site other than LANL with low seismic risk, such as Pantex, would solve seismic issues regarding LANL, although the Virginia earthquake of 2011 raises doubts about the seismicity of any site. The difficulty lies in the tradeoff. LANL has a large human and facility infrastructure for plutonium work; much of that would have to be built from scratch at Pantex Plant (TX), the nuclear weapons complex site that performs final assembly and initial disassembly of nuclear weapons, taking considerable time and involving considerable expense. Savannah River Site has a plutonium waste infrastructure, but not the equipment or personnel for weapons manufacture. Its seismicity is in the same range as that of Los Alamos.[95] Further, while the regulatory issues of dealing with plutonium buildings are well known for LANL, they would have to be examined in detail at another site. Siting, permitting, and preparing an EIS would be time-consuming. In addition, this option would not resolve problems with design, construction, and cost of the building itself.

If building a new building at another site has problems, what about using another existing building at LANL …

Option 5. Refurbish the Chemistry and Metallurgy Research (CMR) Facility

CMR currently performs some AC for pit production in PF-4, as well as nuclear forensics. Given that these are the only two facilities at Los Alamos contributing to pit production, and that it will be many years before a new one could be built, CMR is being maintained at a minimal level in order to keep it operational until approximately 2019, at which point NNSA plans to halt plutonium work there. One option would go beyond currently-planned maintenance and upgrades so as to keep it in operation longer. Just as PF-4 is being upgraded on an ongoing basis to reduce the risks of building collapse and fire, keeping it in operation until 2039, more substantial upgrades to CMR might in theory keep it in service well beyond 2019. So doing would provide AC and other capability until a new building could be built.

This option has many problems and uncertainties. As noted, a congressional commission called CMR "genuinely decrepit" and a DNFSB study found it to be "structurally unsound." Multiple wings of the building have been stripped to bare walls and floors to reduce nuclear material and prepare for decommissioning. A manager at Los Alamos indicated that CMR was built to the standards of the 1950s and there is a "vast mismatch" between the safety requirements of then and now. This individual pointed to problems with heating, electrical, and ventilation systems, and stated that refurbishing the ductwork would be "cost-prohibitive."[96] A tour of the building in September 2013 by the author revealed drains that had been concreted shut, gloveboxes with plastic bags instead of drain connections, gloveboxes with little to no anchoring to the floor, patches to pipes to keep them in operation, and water leaks in the ceiling. Laboratory staff stated that utility panels behind walls were contaminated with radioactive material and that corrosion in some piping had greatly reduced the inside diameter. Since NNSA plans to halt CMR operations in approximately 2019, there have been no studies of how to extend its service life well beyond that time, or what it would cost to do so.[97] However, the fatal flaw in this option is that CMR

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[95] Mehmet Celebi and Robert Page, "Monitoring Earthquake Shaking in Federal Buildings," U.S. Geological Survey Fact Sheet 2005-3052, http://pubs.usgs.gov/fs/2005/3052/.

[96] Telephone interview, April 21, 2010.

[97] Information provided to the author while on a site visit to Los Alamos National Laboratory, September 11-12, 2013.

lacks seismic robustness. Given these problems, it appears that retrofitting CMR to provide adequate utility and seismic robustness may not be possible at any reasonable cost.

Despite these problems, if no other facility is ready to do the work of CMR by 2019, there would appear to be no other option than keeping CMR operational beyond that date, which would entail additional costs, inefficiencies, and the risk of keeping workers in a seismically fragile structure.

Given problems with some obvious options, are other options available? A logical construct matching tasks to buildings may help …

Options 6-12 Overview: Matching Plutonium Tasks to Buildings

Table 2. Matching Plutonium Tasks to Buildings

	Hazard Category (HC)	
Security Category (SC)	**High (HC-2)**	**Low (HC-3)**
High (SC-I/II)	Task: Pit destruction (ARIES) and casting Building: PF-4 or a module (new)	null set (no plutonium tasks require this combination of attributes)
Low (SC-III/IV)	Task: Plutonium-238 work Buildings: HB Line, H Canyon, PTPF (new) at SRS; Building CPP-1634 (expanded) at INL; module at LANL (new)	Task: AC, some MC Buildings: RLUOB with 1 kg WGPu, Building 332 at LLNL, F/H Laboratory or Building 773-A at SRS

Source: CRS.

Notes: AC, analytical chemistry; MC, materials characterization; RLUOB, Radiological Laboratory/Utility/Office Building; WGPu, weapons-grade plutonium; LLNL, Lawrence Livermore National Laboratory, INL, Idaho National Laboratory; SRS, Savannah River Site; PTPF, Plutonium Testing and Processing Facility; CPP, Chemical Processing Plant (a historical name for the site in which the building is located).

As **Table 2** shows, plutonium work may be divided into tasks requiring low or high security, and tasks involving lower- or higher-hazard quantities of MAR. This overview discusses each cell.

High SC/High HC: Most work on pits, whether fabricating them using foundries, performing such supporting tasks as sample prep and some MC, or destroying them using ARIES, involves large amounts of WGPu in a form that could be immediately usable by terrorists. As such, this work requires high security and high MAR. PF-4 is HC-2/SC-I, and has the necessary equipment and supporting infrastructure for pit work. PF-4 is the only building in the nuclear weapons complex with this combination of attributes. Therefore, the most efficient use of PF-4 is for tasks requiring high MAR and high security. As a corollary, pit production capacity and efficiency can be increased by moving tasks that do not require high MAR and high security out of PF-4.

Low SC/High HC: Producing 80 ppy would require casting more hemishells, increasing MAR substantially. While LANL has not done a detailed analysis, this added MAR could raise PF-4 above the limit allowed by the Documented Safety Analysis unless countervailing steps are taken. One approach, discussed in Option 12, would be to build a new module at LANL to hold the pit foundry. A second approach, discussed in Options 6 and 12, is to move Pu-238 work out of PF-4 to a module at LANL or to another site. Pu-238 is an ideal "candidate" to be moved out of PF-4. It is 275 times as radioactive as Pu-239, and even though it is a small fraction of plutonium by weight in PF-4, it accounts for 40 percent of its MAR allowance.[98] It is in a low security category because it would be unattractive to terrorists. Moving Pu-238 out of PF-4 would also free up 8,000 sf of floor space, which could be made available for pit work.

Low SC/Low HC: Casting hemishells for 80 ppy would also require increasing floor space dedicated to that task. AC is floor-space intensive. At the same time, it involves low MAR; indeed, the MAR is so low, and the form of the material (typically tiny samples of plutonium dissolved in acid) of so little value for use in a nuclear weapon if captured by terrorists, that much less security is required than PF-4 provides. The same holds for MC using samples of several grams of metallic plutonium. Accordingly, AC and some MC can be performed in SC-III/IV buildings. Thus, floor space could be made available in PF-4 by performing AC and some MC elsewhere. Manufacturing 10 ppy in PF-4 would have required 2,400 sf of floor space for AC in PF-4, plus about 7,000 sf for AC in RLUOB. The amount in PF-4, 2,400 sf, is a small fraction of that building's space, but since AC for 80 ppy would require considerably more floor space and ventilation capacity, the key value of conducting AC elsewhere would be in keeping additional AC from moving into PF-4. Options for moving AC out of PF-4 are discussed in Options 7-11. Moving the PF-4 gas gun (see **Figure 12**) out of that building and into a building for AC would release 1,200 sf of floor space, and a small amount of MAR, from PF-4.

In sum, moving (and keeping) AC and some MC out of PF-4 would free up space but little MAR, while moving Pu-238 out of PF-4 would free up substantial space and MAR. In combination, these measures would free up much space and MAR in PF-4, making it more likely that it could produce 80 ppy and conduct other plutonium work.

High SC/Low HC: This is a null set; no plutonium tasks require high security for low MAR.

A note on vault storage space: A vault for storing plutonium is an integral part of pit production. It acts as a buffer to hold plutonium because one production task may not dovetail precisely with another. For example, pit production requires a place to hold plutonium metal that has been qualified for use in pits until it is needed, to hold hemishells until they can be joined into completed pits, and to hold completed pits until they are shipped to Pantex for incorporation into weapons. A vault is also needed to store pits from weapons that have been returned from deployment sites for surveillance. PF-4 is the only building at Los Alamos with a vault qualified to hold the large quantity of plutonium that such tasks require.

When CMRR-NF was being designed in the early 2000s, SNM vault space at PF-4 and other sites was mostly filled and the final disposition of material from other sites was unknown. Accordingly, NNSA decided to add vault space to CMRR-NF. RLUOB could not have a vault because it was designed as a Radiological Facility. At issue is whether there is enough vault space in PF-4 to support production of 80 ppy.

Over many years, the PF-4 vault has accumulated much material that is no longer needed for programmatic operations. Some, in excess to current or foreseeable needs, can be de-acquisitioned and shipped to the Waste Isolation Pilot Plant for permanent disposal, to Savannah River Site for other disposition, or to Y-12 for uranium items. Plutonium that might be needed for future operations could be stored elsewhere, such as Pantex Plant, which stores thousands of pits,

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[98] Information provided by Los Alamos National Laboratory, October 23, 2013.

or the Device Assembly Facility at the Nevada National Security Site, an HC-2/SC-I facility that has space available for storage of plutonium, or the K Reactor at Savannah River Site, which is currently used to store plutonium. Thus there are many ways to reduce the amount of material stored in the PF-4 vault, and NNSA accelerated vault cleanout as a mitigation effort associated with the deferral of CMRR-NF. Cleaning out the vault at PF-4 will make more room available for plutonium needed for production. LANL has not studied whether cleanout would provide enough space to support production of 80 ppy, but it appears likely that an effort focused on this goal and coordinated with other sites could do so. Since additional PF-4 vault space could readily be made available and it is not known how much would be needed to support production of 80 ppy, this report does not discuss increasing available vault space as a separate option.

*As a first step in moving through the options presented in **Table 2**, perhaps NNSA could …*

Option 6: Conduct Plutonium-238 Work at INL or SRS

Pu-238 accounts for 40 percent of the MAR allowance at PF-4. Increasing pit production to 80 pits per year (ppy) would increase MAR, and the increased pit foundry work, combined with Pu-238 work and other work, could exceed the MAR limit permitted for PF-4. One option would be to move Pu-238 work out of PF-4, whether to a module connected to PF-4 or to another site. While LANL is DOE's center of excellence for plutonium, Pu-238 work is readily separable from Pu-239 work because the two isotopes have very different properties and applications. Pu-239 is used in weapons and might be used as mixed oxide fuel (a mixture of oxides of Pu-239 and uranium isotopes) for nuclear power reactors, while kilogram quantities of Pu-238 are used to generate heat for conversion to electric power for defense and space missions.[99]

In a report of May 2013, DOE examined several options for processing Pu-238 for fabrication of radioisotope power systems.[100] One was to upgrade the existing line in PF-4; however, this would not address the possibility of reducing Pu-238 MAR in order to release MAR for weapons work. The report also considered performing Pu-238 work at Idaho National Laboratory (INL) or Savannah River Site (SRS). It did not address the LANL proposal to build modules connected to PF-4, one of which might perform Pu-238 work.[101]

INL currently conducts operations with clad heat sources of Pu-238. It operates the Space and Security Power Systems Facility, which further encapsulates the Pu-238 heat sources produced by LANL, mates them to the power systems that convert their heat to electric power, tests the resulting system, and delivers them to users.

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[99] For example, the National Aeronautics and Space Administration (NASA) Cassini mission, which used more Pu-238 than any other NASA mission, used a total of 23.8 kg of Pu-238 in three radioisotopic thermoelectric generators. Email from NASA, November 12, 2013.

[100] U.S. Department of Energy. Space and Defense Power Systems. Radioisotope Heat Source Infrastructure Review Team. "Evaluation of Radioisotope Fuel Processing and Heat Source Fabrication Infrastructure Capabilities, Final Report," May 2013.

[101] INL and SRS staff provided information on the possible use of their facilities for this option, personal communications, October 24 and 31, 2013.

Figure 7. Building CPP-1634

At Idaho National Laboratory

Source: Idaho National Laboratory.

INL states that all current LANL Pu-238 operations could be transferred to INL, such as recovery, purification, and source fabrication, and that INL would have a capacity of processing 5 kg per year. The option to bring Pu-238 source fabrication to INL would use an existing building, CPP-1634, that was built in 1993 as an HC-2 building and was since downgraded.[102] It would have to be upgraded back to HC-2 in order to handle 5 kg of Pu-238 per year.[103] INL would also build an addition to CPP-1634 that would more than double its size. The upgrade would require modifying the safety analysis report and upgrading the building's safety systems (such as ventilation) and equipment (such as gloveboxes) to be consistent with the hazards and operations proposed.[104] Pu-238 in quantities of up to 16 kg is SC-III because it is unattractive for use in making a nuclear weapon. CPP-1634 would have more security than is needed to meet SC-III requirements because it would be within the INL security perimeter.

The DOE report noted several advantages of establishing this capability at INL, including a new design that minimizes down time and maintenance cost, and process improvements that minimize operational costs and worker exposure and improve product quality. Also, locating the program in a facility owned by DOE's Nuclear Energy program, which is responsible for plutonium-238, would allow "more control and lower operational costs as compared to operating within TA-55 that seems to have large overhead costs resulting in high operational costs." Drawbacks include "inexperience with Pu-238 processing operations," "loss of co-location and leveraging with related NNSA program," risk due to uncertainty in safety requirements because "no new Pu-238 processing facility has been constructed in many years," and "risk of moving Pu-238 operations away from DOE's plutonium operations center of excellence," i.e., LANL.[105]

There is also an SRS option. From the mid-1960s to early 1980s, SRS produced Pu-238 in its reactors by bombarding neptunium-237 target tubes with neutrons. It then dissolved the target tubes, separated and purified Pu-238 in H Canyon, turned the Pu-238 into plutonium oxide in HB-Line, pressed that material into heat sources, and clad them in iridium in the 235-F facility. In 1983, the last neptunium-237 targets were irradiated and in 1985-1986, Pu-238 operations were

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[102] "CPP" stands for Chemical Processing Plant, a historical name for the site.

[103] Pu-238 is 275 times more radioactive than Pu-239, so 5 kg of the former has the same level of radioactivity as 1,375 kg of the latter.

[104] Because Pu-238 is an intense emitter of neutrons and gamma rays, people working with it require shielding, so the work could not be done in open-front hoods or standard gloveboxes.

[105] Department of Energy, "Evaluation of Radioisotope Fuel Processing and Heat Source Fabrication Infrastructure Capabilities, Final Report," pp. 4-2, 4-3.

moved to LANL. Subsequently, the last SRS reactor was shut down in 1993. Work is underway to develop the capability to produce Pu-238 at Oak Ridge National Laboratory (TN).[106]

SRS has two buildings that could be used for Pu-238. Its H Canyon is a large, highly shielded concrete structure, approximately 1,000 feet long by 120 feet wide by 75 feet high, that began operations in 1955. It was built to process irradiated targets and fuel rods from SRS reactors for various nuclear materials. These targets and fuel rods had very high levels of radioactivity, so they required processing in a facility that was heavily shielded and remotely operated. As such, it is off limits to personnel, and all material is processed by moving it through pipes or handling it with a remotely-operated crane. It is the only remaining U.S. facility that is heavily shielded and remotely operated and that can chemically process large quantities of radioactive material, such as spent fuel rods. It is currently operational, processing irradiated fuel stored in an underwater pool at SRS. SRS also has the HB-Line, which is built atop H Canyon to provide a work space with heavily-shielded gloveboxes for work on Pu-238. It became operational in the late 1980s. It is currently operating, but its Pu-238 lines would have to be restarted, which could take three or four years. A third building at SRS that was used in the Pu-238 program, Building 235-F, contained a process line that fabricated heat sources from Pu-238 oxide. However, the facility has not been operated since 1984 and is not part of the current proposal due to high levels of contamination.

In the SRS plan, Pu-238 could arrive at the plant as irradiated target tubes of neptunium-237 from a DOE reactor, as unpurified Pu-238 oxide from Russia, or as scrap Pu-238 oxide.[107] These oxides would be dissolved in nitric acid in the HB-Line. This solution would be transferred through pipes to H Canyon, where it would be purified by removing other chemical elements. The purified Pu-238 solution would be transferred back to HB-Line, where plutonium would be precipitated out of solution and then turned into plutonium oxide, a solid. In an option in the SRS plan, a new Plutonium Testing and Processing Facility (PTPF), consisting of prefabricated hot cells (capable of handling highly radioactive material) and gloveboxes, would be installed in H Canyon. This facility would press plutonium oxide into pellets, which would be fabricated into heat sources, clad in iridium, and sent to INL, where they would be mated with power generating equipment and then delivered to end users.

The DOE report noted several advantages and disadvantages of this option. H Canyon and HB-Line can process a wide quantity range of Pu-238, from 1 to over 30 kg per year. These facilities are built to high safety standards. Infrastructure requirements are well understood, such as environment, safety, and health, material control and accountability, and waste management; there is also an AC capability. On the other hand, the length of time that missions will support H Canyon is not clear because "its mission length is defined by a campaign by campaign basis." Operations there are planned until 2018-2020, with operations beyond that time uncertain.

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[106] "ORNL's plutonium-for-space project on pace," Frank Munger's Atomic City Underground (blog), December 26, 2013, http://knoxblogs.com/atomiccity/2013/12/26/ornls-plutonium-space-project-pace/.

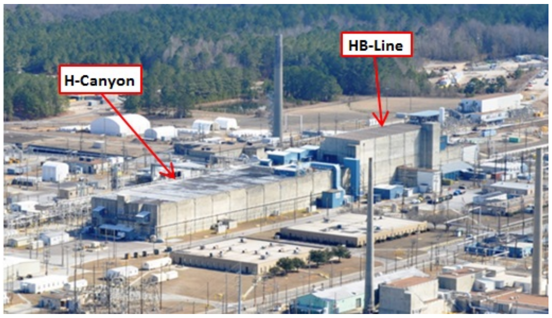
[107] The United States has reportedly purchased Pu-238 (in oxide form) from Russia since the 1990s. See Geoffrey Brumfiel, "Curiosity's Dirty Little Secret," *Slate,* August 20, 2012, http://www.slate.com/articles/health_and_science/science/2012/08/mars_rover_curiosity_its_plutonium_power_comes_courtesy_of_soviet_nukes_.single.html. However, this material still requires the plutonium-238 operations carried out in the United States, such as removing impurities, fabricating plutonium oxide into ceramic pellets, and encapsulating the fuel in cladding.

Further, required production "[does] not necessitate a large throughput capacity. Thus, revitalization of the facilities may not be justified." And without a long-term mission, there is no clear advantage to building PTPF.[108] At issue: There is value to the weapons program in removing Pu-238 from PF-4. Would processing Pu-238 be a long-term mission that would justify, and that might contribute funding to, PTPF?

The DOE report compared cost and schedule estimates for these two options, as follows.[109]

Figure 8. H Canyon and HB-Line

At Savannah River Site



Source: Savannah River Site.

Notes: The photo shows HB-Line atop H Canyon.

- For the INL option, $12 million for technology development taking three years, and $110 million to $260 million for general-purpose heat source fabrication capability, taking five years.
- For the SRS option, $28 million to $45 million for plutonium purification revitalization, taking 3½ to 4½ years, and $125 million to $170 million for PTPF, taking four to five years.
- Combining these figures, the INL option would cost $122 million to $272 million and take eight years, and the SRS option would cost $153 million to $215 million and take 7½ to 9½ years.

It must be emphasized that these estimates are preliminary and are not based on extensive analysis.

DNFSB commented that "H-Canyon is exhibiting degradation of systems and structures that if not addressed, could challenge safe operations and pose a risk to facility workers. … DOE completed repairs to address some of the identified deficiencies … There are some safety-related repairs that have not yet been completed."[110]

Having addressed Pu-238, this report now turns to options to address analytical chemistry …

Option 7: Conduct Some or All Analytical Chemistry at LLNL or SRS

Lawrence Livermore National Laboratory (LLNL) has a large building, Building 332, that is part of its "Superblock" complex.[111] Building 332 was built for plutonium work. One wing

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[108] Department of Energy, "Evaluation of Radioisotope Fuel Processing and Heat Source Fabrication Infrastructure Capabilities, Final Report," May 2013, p. 4-4.

[109] Ibid., p. 3-6.

[110] U.S. Defense Nuclear Facilities Safety Board. "Summary of Significant Safety-Related Aging Infrastructure Issues at Operating Defense Nuclear Facilities." Fourth Annual Report to Congress, Enclosure, p. E-8, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Reports%20to%20Congress/2013/ar_20131030_23051.pdf.

[111] This section is based on discussions with Livermore and Los Alamos staff, October 2013. For information on Superblock, see Joseph Sefcik, "Inside the Superblock," *Science & Technology Review* (a Lawrence Livermore National Laboratory publication), March 2001, https://www.llnl.gov/str/March01/Sefcik.html.

("Increment 1") was built in 1961; another wing ("Increment 3") was built in 1975. Increments 1 and 3 are laboratory buildings; Increment 2 is the control room, without laboratory space. Building 332 was a Hazard Category 2/Security Category I facility, like PF-4, so it was used to handle hundreds of kilograms of plutonium. Its ventilation systems (including fans and HEPA filters) and electrical systems have been updated in the past decade. Even though Livermore is in a seismically active area, Building 332 was designed to take into account seismicity, and an analysis showed that it does not require an upgrade to make it more seismically robust. Its gloveboxes (new and retrofitted) are reinforced so as not to fall over in an earthquake.

Building 332 remains an HC-2 building, but its plutonium quantity is limited by its Security Category. It was SC-I. To reduce vulnerability and security costs, NNSA consolidated SNM to fewer facilities at fewer sites. As part of that plan, LLNL removed all SC-I/II quantities of SNM from the lab, a task completed in September 2012.[112] Building 332 is now SC-III, which limits it, as a first approximation, to 400 g of plutonium metal and 16,000 g of plutonium in solution.[113] Plutonium in solution poses much less risk—is less attractive to terrorists—than metallic plutonium, which is why much more plutonium is allowed in solution than in metal form.

Building 332 has ample space for AC work. It has 24,000 total sf of laboratory space, as compared to 19,500 sf for RLUOB and 22,500 sf in the CMRR-NF design. Some space is being used to fabricate plutonium samples for experiments that subject plutonium to impact (such as from a gas gun projectile) and for material processing studies. LLNL is currently using 5,000 sf for AC and MC, and could make another 6,000 sf available. Building 332 has a substantial excess of air handling capacity, which would support the use of open-front hoods. LLNL believes that Building 332 has sufficient air handling capacity to support AC for 80 ppy.[114]

Once analyzed, samples would be processed as waste. For final disposition, waste is shipped to WIPP. Since WIPP does not accept liquids, liquid waste is solidified by mixing it with cement. LANL and LLNL differ in how they would handle waste. LANL has the capability to recover plutonium from liquid samples and to process the waste stream, solidifying it for shipment to WIPP. LANL uses AC to support these operations. LANL also uses AC to send liquid waste to LANL's Radioactive Liquid Waste Treatment Facility because that facility places requirements (such as the amount of mercury) in the waste it accepts for treatment. LLNL does not have these capabilities, and would not perform AC on material (liquids and solids) to be disposed of as waste. However, the liquid waste generated by the AC for 80 ppy would be very much less than the waste that LANL generates for various other missions, so LLNL holds that simply cementing the liquid waste would be a satisfactory way to prepare its liquid waste for shipping.

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[112] U.S. Department of Energy. National Nuclear Security Administration. "NNSA Completes Removal of All High Security Special Nuclear Material from LLNL," press release, September 21, 2012, http://nnsa.energy.gov/mediaroom/pressreleases/snmremoval092112.

[113] More precisely, the upper bound for SC-III is as follows: the sum of the weight of plutonium metal plus 1/3 the weight of such other materials as plutonium oxide must be less than 400 grams *and* the weight of plutonium in solution (of up to 25 grams of plutonium per liter) must be less than 16,000 grams. See U.S. Department of Energy. Office of Security and Safety Programs Assurance. Nuclear Material Control and Accountability. Manual DOE M 470.4-6, Change 1, August 14, 2006, Section A, pages I-8 through I-11.

[114] Information provided by Lawrence Livermore National Laboratory, December 27, 2013.

Figure 9. Building 332

At Lawrence Livermore National Laboratory

Source: Lawrence Livermore National Laboratory,

Note: "Superblock" is the entire fenced area.

There are several potential drawbacks. All DOE sites that handle plutonium have their own AC operations rather than shipping samples to another site because AC is a basic capability required for many purposes in addition to pit manufacturing, such as measuring quantity of material for material control and accountability, recovering plutonium from waste streams, and for various types of pit work including development of processes for fabrication, qualification of processes, and certification. At issue is whether LLNL would have the needed capacity to support AC for 80 ppy while performing AC for other missions. Having LLNL perform the AC could add schedule risk to any LLNL program that needed AC.

While commercial carriers have shipped plutonium for some years, there might be public concern about shipping many hundreds of samples per year. As a related point, while LLNL could stay within MAR limits if plutonium shipments arrived weekly, a LANL engineer observed, "I have been associated with pit manufacturing for several decades and it hasn't ever reached steady state yet. The notion of standardized delivery dates is inconceivable to me. The manufacturing process is too fragile and is constantly interrupted leading to feast or famine sample delivery."[115] Further, it takes five days to dissolve a certain type of plutonium samples (plutonium oxide fired at very high temperature). Might these problems result in exceeding MAR limits?

Performing all AC work in support of pit production would bring more plutonium work to LLNL. This would have the advantage of distributing plutonium expertise more widely in the nuclear weapons complex. LLNL currently has only four chemists doing AC on plutonium. This option would require adding staff and equipment, strengthening LLNL's capability, which could prove useful for peer review of plutonium issues as well as for AC. On the other hand, LANL is the center of excellence for plutonium in the nuclear weapons complex, and this option would dilute LANL's plutonium capability. According to a LANL staff member,

> If all DOE sites were making steel, there would be ample opportunities to consolidate AC using commercial vendors. With plutonium, AC is too inherent to processing for one site to be completely reliant on off-site AC measurement. Manufacturing war reserve pits demands the highest quality level and the broadest suite of analytical techniques. Since LANL has the country's main plutonium facility, it would need substantial in-house AC capability, and there is inherent capacity in the capability. The logistics of a split-capability mission (manufacturing at LANL, AC elsewhere) does not seem amenable to a smoothly operating enterprise. That said, LANL's 2012 "60-day study" acknowledged that LLNL could perform some AC when LANL needed additional capacity.[116]

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[115] Personal communication, October 30, 2013.

[116] Personal communication, Los Alamos National Laboratory, October 30, 2013. The 60-day study is Leasure, C. L., M. M. Nuckols, et al., "Los Alamos Initial Response for Maintaining Capabilities with Deferral of the CMRR Nuclear Facility Project," Los Alamos National Laboratory, LA-CP-12-00470 (UCNI), April 16, 2012. The study is categorized (continued...)

Savannah River Site (SRS) offers another option. It has been involved with plutonium for many decades. It had five large reactors for producing plutonium, the first of which began operations in 1953. In total, these reactors produced 36 metric tons of plutonium, most of which was WGPu, with the largest annual amount, 2.1 metric tons, produced in 1964.[117] All the plutonium produced had to be characterized, which required AC. Because SRS supplied plutonium to Rocky Flats Plant, SRS needed an industrial-scale AC capability to characterize the plutonium for the weapons program and to perform AC for other tasks, such as for Pu-238. Part of this capacity is currently unused, but SRS retains the infrastructure and equipment.

While SRS no longer produces plutonium—an SRS reactor last produced plutonium in 1988—SRS continues to conduct a great deal of plutonium AC. It has repurposed its K Reactor, which used to produce plutonium, to store tons of plutonium from across the nuclear weapons complex and elsewhere. For example, plutonium from Rocky Flats and the Hanford Reservation (which used to produce plutonium) was moved to the K Reactor, as was plutonium de-inventoried from LLNL in order to move Superblock to Security Category III, plutonium oxide produced from retired pits by ARIES at PF-4, and plutonium from foreign sources. More is being added on an ongoing basis. All this plutonium requires AC in order to characterize the isotopic composition and impurities of plutonium stored in drums at K Reactor. For example, AC would detect chlorides and fluorides in the plutonium mixture that would corrode storage drums. AC is also used for characterizing plutonium produced at HB-Line for use in mixed oxide (MOX, a blend of plutonium oxide and uranium oxide) fuel for nuclear reactors.

As with many industrial operations, SRS nuclear materials processing facilities operate 24/7, so SRS conducts AC 24/7 because some processing operations require a short turnaround time for AC, and personnel must be available at all times in case of problems.

Figure 10. F/H Laboratory

At Savannah River Site

Source: Savannah River Site.

SRS currently uses F/H Laboratory (the laboratory that supported H area, where H Canyon and HB-Line are located, and F area, which also has a canyon and a B-line) for AC. F/H Laboratory (see **Figure 10**) is large, 80,000 sf as compared to 60,000 sf for PF-4 and 19,500 sf for RLUOB. Also at SRS is Building 773-A, which is larger than F/H Laboratory. Since both labs were sized for a time when the United States produced many thousands of nuclear weapons, they have between them a great deal of excess capacity in terms of hoods and gloveboxes for AC. SRS believes that F/H Laboratory, with Building 773-A for redundancy or a spike in workload, could handle the AC for 80 ppy, though they would need some new instruments and SRS would have to hire perhaps 20 technicians and several analytical chemists. Both labs have a very large ventilation capacity. For example, F/H Laboratory is equipped with six large fans, but SRS calculated that two of them could be shut down and the others would still provide sufficient ventilation capacity. SRS could perform the AC and Pu-238 missions concurrently, as they would

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(...continued)

as unclassified controlled nuclear information, so is not available for use in this report.

[117] U.S. Department of Energy. *Plutonium: The First 50 Years,* DOE/DP-0137, February 1996, pp. 25, 33, http://www.doeal.gov/SWEIS/DOEDocuments/004%20DOE-DP-0137%20Plutonium%2050%20Years.pdf.

use different facilities—H Canyon and HB-Line for Pu-238, and F/H Laboratory, Building 773-A, or both for AC.

SRS has worked closely with LANL on AC. SRS is part of LANL's quality assurance program. LANL sends SRS metal samples once a year for SRS to perform AC on as part of the Plutonium Metal Standards Exchange. In that program, multiple sites, including the United Kingdom's Atomic Weapons Establishment, exchange plutonium samples and perform AC on them as a check on each other's AC capabilities. LANL, through its accreditation program, has also qualified SRS to perform the AC for plutonium to supply the MOX plant.

The drawbacks of conducting all AC for 80 ppy at SRS are similar to those discussed for LLNL, though LANL would not be opposed to conducting some AC at another site if it needed extra capacity to handle a spike in workload, or on a routine basis if production increased to 80 ppy.

Many plans proposed over the past two decades for plutonium work have sought to consolidate that work at a single site. If it is deemed desirable to do as much plutonium work as possible at LANL, what about a deeper look at other LANL options, starting with an existing building …

Option 8. Use RLUOB As Is for Analytical Chemistry, with PF-4 Conducting the Balance of Pit Work

Under this option, PF-4 would produce pits and would do sample preparation, waste disposal, and MC, while RLUOB would conduct AC on 26 g of WGPu, the most allowed by the Hazard Category material limit for a Radiological Facility. While RLUOB is ideally suited for AC, this option suffers from one significant flaw: 26 g of WGPu is nowhere near enough to do the AC to support 80 ppy, and PF-4 does not have the space to do most of the AC, all of the MC, all of the pit fabrication, other pit work, and work on other plutonium projects.

While RLUOB as is could not conduct the AC/MC needed under current regulations, would it be possible to …

Option 9. Convert RLUOB to Hazard Category 3 for Analytical Chemistry

Recently developed Los Alamos plans for PF-4 include upgrading wings of the building for Pu-238 operations, pit disassembly, pit fabrication, and other programs. Of particular importance are the upgrades to the pit fabrication wing of the building. These upgrades will remove currently-unused gloveboxes from the manufacturing space, consolidate laboratory space, and improve the equipment layout to enhance process flow. These steps would increase PF-4's pit production capacity. CMR, RLUOB, or both would conduct some AC necessary to support pit manufacture.

Space consolidation offers an opportunity to repurpose space to add equipment to achieve capacities of up to 80 ppy for several, but not all, flowsheet operations. (A "flowsheet" is a sequence of operations that must be followed precisely to make a pit.) The capacity of other operations could be boosted in other ways, such as by adding shifts. The challenge is determining what actions are needed to ensure that every operation in the flowsheet could handle up to 80 pits per year because there is not enough space in PF-4 to scale all operations, including support operations like AC, up to a capacity of 80 ppy.

Figure 11. Volume of Weapons-Grade Plutonium Allowed in RLUOB

DOE regulations permit up to 38.6 grams of plutonium-239 equivalent in a Radiological Facility, which equates to about 26 grams of weapons-grade plutonium. The latter amount in one metallic form (alpha phase) has a volume of **1.31 cubic centimeters, a little less than that of two nickels.**

Source: Image, U.S. Mint; graphic, CRS.

LANL has not analyzed space-fit issues for producing 80 ppy. But based on comparison to past analyses, it seems likely that achieving a capacity of 80 ppy in PF-4 is possible if LANL could fully use the laboratory space in RLUOB. The usefulness of that space, 19,500 square feet, is currently limited by a requirement that RLUOB can hold only 26 g of WGPu, the volume of two nickels. (See **Figure 11**.) Increasing that limit to 1,000 g would provide enough MAR in RLUOB for the AC to support production of 80 ppy, as well as some MC. It is not clear that RLUOB has sufficient floor space to do that much work. However, as discussed in **Appendix F**, it seems likely that RLUOB with a MAR of 1,000 g WGPu, plus space made available in PF-4 through reconfiguration (8,000 sf) or by moving out Pu-238 (a separate 8,000 sf), plus improving pit fabrication operations (such as by using multiple shifts or improving efficiency of equipment or processes), would provide enough space and free up enough MAR to produce 80 ppy and to perform the AC needed to support that level of production.

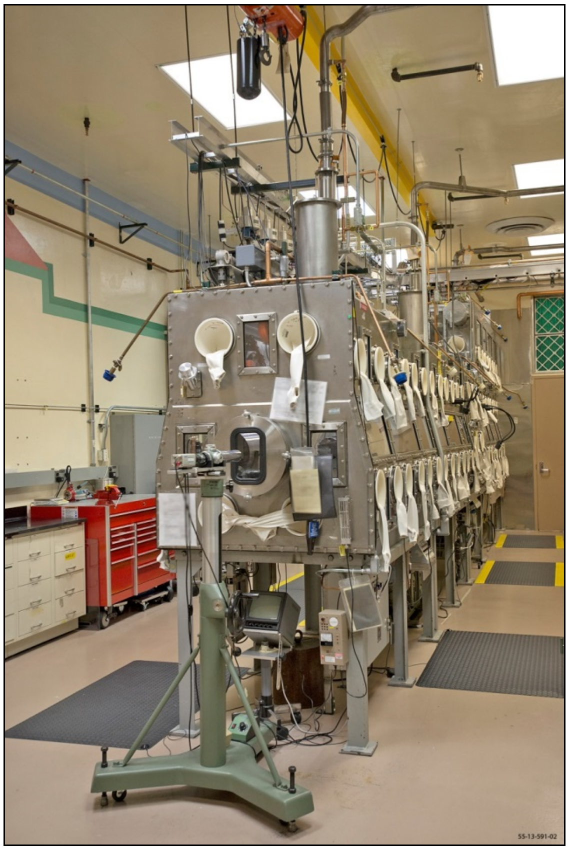
To hold 1,000 g WGPu while complying with regulations, RLUOB would have to be converted to an HC-3 building. There are several advantages. So doing would support LANL's ability to perform the pit work that DOD requires. It would permit LANL to move AC equipment from CMR, enabling that building to halt plutonium operations. It would permit LANL to free up floor space in PF-4 by moving out equipment for AC and for some MC (see **Figure 12**), and to make operations more efficient, such as by moving out a large MC instrument now placed in the middle of an AC room.

A drawback is that it would take a substantial effort to convert RLUOB to HC-3. As a Radiological Facility, RLUOB is not subjected to federal, state, local, and laboratory requirements for an HC-3 building. To comply with these requirements, many tasks would have to be conducted; **Appendix D** lists about 100 of them. Many, such as preparing an environmental assessment and perhaps an EIS, developing safety design reports, developing engineering functions and requirements documents, developing an updated fire hazards analysis, and developing a final material control and accountability plan, would require much time and effort; others would require less effort. But the work would not stop with preparing these documents because many would lead to physical modifications to RLUOB. For example, an engineering task listed in **Appendix D**—"Develop design and analysis for seismic upgrades as required. RLUOB safety Structure, System and Components (SSCs) are not currently required to be operational following a seismic event per [NNSA's Los Alamos Field Office] direction"—could easily lead to seismic upgrades to RLUOB unless a decision were made to accept the risk in light of cost-benefit considerations.

LANL has not estimated the cost or schedule to complete these tasks, and the upgrade could prove to be expensive. However, given the historical record of cost growth, schedule delays, cancellations, and deferrals in constructing new plutonium facilities, upgrading RLUOB to HC-3 would probably be a quicker and less costly way to obtain the needed capacity than building a new building.

Regulations limit the quantity of WGPu that RLUOB can hold to the volume of two nickels. What would happen if that limit were not applied to RLUOB?

Figure 12. A Gas Gun in PF-4



Source: Los Alamos National Laboratory.

Notes: The gloveboxes in this photo enclose a 40-mm gun that is loaded at the breech (nearest end) with an explosive charge or pressurized gas to propel a slug of metal through the gun barrel. At the far end, the slug slams into a small piece (20 to 25 grams) of plutonium metal. Each shot provides data on the performance of plutonium under dynamic impact, which is useful for assessing how plutonium behaves in a nuclear weapon. These experiments provide data for materials characterization, i.e., data on bulk properties of plutonium.

Moving this gun out of PF-4 would free up 1,200 square feet of laboratory space that could be used for other missions. In addition, diagnostic equipment for the gun is located in the basement of PF-4 directly underneath the gun. Removing that equipment would free up 900 square feet of space that could be put to other uses, such as temporary storage of drums containing plutonium waste for shipment to WIPP.

Option 10. Use RLUOB, with Regulatory Relief, for Analytical Chemistry, with PF-4 Conducting the Balance of Pit Work

Many regulations impose burdens on the nuclear weapons complex, including plutonium facilities, that to some analysts may seem disconnected from end goals, such as reducing dose in the event of an accident to a level below a specified threshold. Two quotes are instructive; many more could be added. SEAB stated in 2005,

> The DOE has burdened the Complex with rules and regulations that focus on process rather than mission safety. Cost/benefit analysis and risk informed decisions are absent, resulting in a risk-averse posture at all management levels.[118]

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[118] Secretary of Energy Advisory Board, *Recommendations for the Nuclear Weapons Complex of the Future,* p. vi.

And an NNSA report of 2006 stated that the complex of that time had

> A culture that sometimes seeks to eliminate all risks at an unsustainable cost no matter how small the probability of occurrence and to substitute oversight recommendations for responsible line decisions.[119]

Hazard Category regulations limiting the amount of plutonium in a building are intended to limit the dose to emergency responders, collocated workers and the general public. However, a calculation in **Appendix B** shows that if RLUOB held 1,010 g of WGPu and a Design Basis Accident occurred in which the building collapsed, the dose for a collocated worker (CW) and a maximally-exposed offsite individual (MOI) would be far less than the guideline set forth in DOE regulations. Specifically, the dose to a CW would be 10.41 rem, vs. a guideline of 100 rem, and the dose to an MOI would be 0.49 rem, vs. a guideline of 5 to 25 rem.[120] And as discussed under "Increasing Safety," the probability and consequences of a DBA can be reduced in many ways. Accordingly, Option 10 focuses on how RLUOB might be used for AC/MC in support of pit production if Congress were to waive the limit of 38.6 g Pu-239E (26 g WGPu) for RLUOB.

While the option has not been studied, it appears, as noted under Option 9, that a MAR limit of 1,000 g WGPu would be enough for RLUOB to perform the AC needed to support 80 ppy, as well as some MC tasks, though more floor space might be needed. **Appendix F** shows the space breakout for AC under several plans. CMRR-NF would have had about 22,500 sf of lab space. Of that, 9,750 sf would have been used for AC. Another 6,750 sf in RLUOB would have been used for AC. The current plan, with the 26 g WGPu limit, is to use 10,500 sf in RLUOB and 5,600 sf in PF-4 for AC. However, most AC work is less efficient if done in PF-4 than in RLUOB because PF-4 uses gloveboxes and because PF-4, which is SC-I, requires particularly rigorous security measures. If RLUOB could hold 1,000 g WGPu, 15,000 sf could be used for AC, 3,500 sf for MC, with the remaining 1,000 sf available for support activities. PF-4 could use 2,400 sf for sample preparation, which uses a large amount of plutonium and is done in a small lab room already set up for this purpose in PF-4.

Option 10 may merit further study because, if it proves feasible, it would offer advantages that address concerns Congress has raised for many years. Option 7 (AC at LLNL or SRS) would offer some of these advantages as well.

1. Option 10 would reduce cancellation risk. The history of pit production efforts includes cases where decisions by Congress or the Administration have halted a major plutonium building after planning had started but before construction had

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[119] National Nuclear Security Administration, *Complex 2030,* p. 3.

[120] DOE-STD-3009-94, Change Notice 3, 2008, *DOE Standard: Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses,* Appendix A, "Evaluation Guideline," p. A-2, states that the Evaluation Guideline (the dose that the safety analysis evaluates against) "is 25 rem total effective dose equivalent (TEDE). The dose estimates to be compared to it are those received by a hypothetical maximally-exposed offsite individual (MOI) at the site boundary for an exposure duration of 2 hours. … Unmitigated releases should be compared against the EG to determine whether they challenge the EG, rather than exceed it." DOE-STD-1189-2008, *DOE Standard: Integration of Safety into the Design Process,* Appendix A, "Safety System Design Criteria," p. A-5, states under Public Protection Criteria, "The words 'challenging' or 'in the rem range' in those documents [one of which is DOE-STD-3009-94 Change Notice 3] should be interpreted as radiological doses equal to or greater than 5 rem TEDE, but less than 25 rem TEDE." On pp. A-5 and A-6, under Collocated Worker Protection Criteria, DOE-STD-1189-2008 states, "A conservatively calculated unmitigated dose of 100 rem TEDE has been chosen as the threshold for designation of facility-level Safety SSCs [structures, systems, and components] as safety significant (SS), for the purpose of collocated worker protection."

begun. Conducting pit production support tasks in a building that already exists would reduce this risk.

2. Option 10 would greatly reduce the risk of a plutonium building being built, found unsuitable, and torn down. As described in "Two Other Failed Attempts," this situation occurred with Building 371 at Rocky Flats Plant and the Nuclear Material Storage Facility at LANL.
3. Using RLUOB would reduce the risk of large cost growth. Congress is concerned about NNSA's record of cost growth in its nuclear facility construction projects, which may be why Congress, in the FY2013 National Defense Authorization Act, P.L. 112-239, Section 3114, capped spending for UPF and CMRR-NF, and why Section 3112 of P.L. 113-66, FY2014 National Defense Authorization Act, established a Director for Cost Estimating and Program Evaluation in NNSA. RLUOB has much lab space, and procuring added equipment would not add to the marginal cost if such equipment would be procured for another nuclear facility. Converting more space in RLUOB, strengthening it, or making other changes to reduce risk and increase efficiency would probably not cost as much as a new facility.
4. Equipping RLUOB for AC and some MC would be the fastest way to augment capacity. RLUOB has an infrastructure to support work on small samples, some lab space is already equipped, and empty lab space could be equipped. The capacity should be available before it is needed, providing time to work out process kinks. In contrast, adding equipment to PF-4 would be difficult, costly, and time-consuming because changes to PF-4, an HC-2 building, must comply with many requirements and workers must undergo security checks, and space may not be available. Minimizing the risk of delay is also of value because delay typically increases cost and could disrupt the schedule for weapons work.
5. Section 3114 of the FY2013 National Defense Authorization Act, P.L. 112-239, requires the Secretary of Energy to construct a building to replace the functions of CMR at a cost not to exceed $3.7 billion. If RLUOB could replace the functions of CMR while avoiding the need to build CMRR-NF, it would save the cost of the latter facility, which NNSA estimated at between $3.7 and $5.9 billion in its FY2012 budget request.[121] The savings could be higher. A five-year deferral, NNSA estimates, would add two years to the time to complete CMRR-NF,[122] and delay typically adds cost. CMRR-NF might be canceled in favor of a modular strategy, which Section 3117 of the FY2014 National Defense Authorization Act authorizes. The two modules referenced in Section 3117 would presumably be less costly than CMRR-NF, especially as they would be between 3,000 sf and 5,000 sf, vs. 22,500 sf for CMRR-NF. However, modules would be HC-2 and at least SC-II. As such, the cost of two modules could reach the billions of dollars.
6. Using RLUOB would avoid or minimize design and construction risks, such as design errors. These risks are different than cost and schedule risks, though they may lead to such risks. A case in point from 2013 occurred with UPF. According

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[121] U.S. Department of Energy. Office of Chief Financial Officer., *FY2012 Congressional Budget Request*, Volume 1, National Nuclear Security Administration, DOE/CF-0057, Washington, DC, February 2011, pp. 225, 228, http://energy.gov/sites/prod/files/FY12Volume1.pdf.

[122] Information provided by NNSA, July 2013.

to the Senate Appropriations Committee, "Most recently, a space fit issue that required raising the roof of the building by 13 feet to fit critical equipment resulted in more than $500,000,000 in additional costs to U.S. taxpayers."[123]

7. As **Appendix E** shows, RLUOB is much more seismically resilient than CMR. Option 10 could permit NNSA to halt work in CMR by 2019. It might even permit halting this work before then, reducing the time in which CMR poses a safety hazard to its workers and the public. If no other facility is in place by 2019 for AC and some MC, it might be necessary to extend CMR's service life beyond then. However, there is no assurance that that could be done, which would make it harder to meet the 2021 pit production goal. As a cautionary example, the redesign of UPF might push completion of that facility past the date when Building 9212 can no longer be kept in service.[124]
8. Option 10 could make 1,200 sf of lab space available in PF-4 by enabling the gas gun (see **Figure 12**) to be moved out. The target is typically 20-25 g of WGPu. With a MAR limit of 26 g WGPu for RLUOB, the target would take up so much MAR that much other plutonium work in RLUOB would have to be stop and the material containerized when a gas gun experiment was in progress. A MAR limit of 1,000 g of WGPu would avoid that problem.
9. Option 10 would increase efficiency in other ways. For example, PF-4 houses a highly sensitive spectrometer that had to be placed near an outside wall to minimize vibrations. The only suitable space available was in the middle of a room filled with gloveboxes. Moving it to RLUOB would remove clutter from the room. At the same time, it would be easier to use the instrument in a laboratory room outfitted to accommodate it.
10. NNSA anticipates that upgrades will enable PF-4 to remain in service until 2039. Based on experience with other plutonium buildings, RLUOB, which was completed in 2009, should have at least a 50-year service life. If PF-4 and RLUOB can remain in service for another quarter-century, Congress may be able to defer decisions on other plutonium facilities for at least a decade, and defer substantial expenditures on such facilities longer than that.
11. Even if NNSA ultimately moves high-MAR activities from PF-4 to modules, as discussed in Option 12, it would still be desirable if not necessary to use RLUOB for AC to support production of 80 ppy because RLUOB, unlike PF-4 or the modules, is well suited for low-MAR work that uses a substantial amount of floor space. Thus upgrading RLUOB would likely be a component of the module plan, in which case any difficulties attendant upon upgrading RLUOB would be present under the module plan.
12. Placing the pit program on a fiscally and politically sustainable path soon would avoid years of uncertainty for the entire plutonium program, providing a long-term foundation for the rest of the program. That would help NNSA plan that program, other facilities, disposition of excess nuclear material, and budgets.

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[123] U.S. Congress. Senate. Committee on Appropriations. Energy and Water Development Appropriations Bill, 2014, 113th Congress, 1st Session, S.Rept. 113-47 to accompany S. 1245, June 27, 2013, p. 107. See also Frank Munger, "How Did the UPF Design Disaster Happen?," *Frank Munger's Atomic City Underground,* August 23, 2013, http://knoxblogs.com/atomiccity/2013/08/23/how-did-the-upf-design-disaster-happen/.

[124] Frank Munger, "9212: How Safe for How Long?," *Frank Munger's Atomic City Underground,* July 17, 2013, http://knoxblogs.com/atomiccity/2013/07/17/9212-how-safe-for-how-long/.

13. Upgrading existing buildings, rather than building new buildings or transporting material to other sites as part of pit production, should minimize environmental impact. As a result, compliance with NEPA should be simpler and an EIS prepared to comply with the spirit as well as the letter of that law should be less vulnerable to a successful legal challenge.

At the same time, there are several concerns about this option.

1. RLUOB might collapse in an earthquake. The building was designed to have a 50 percent chance of surviving the 1995 design basis earthquake (DBE), but the 2009 DBE is more powerful. The lowest two floors of RLUOB (basement, utilities; and first floor, laboratory) are built of thick reinforced concrete, and the second floor (lowest office floor) has thick concrete columns; all are seismically robust. The upper two office floors are designed to the structural requirements of an emergency response building, like a hospital or fire station. While the upper two floors are less robust than the lower floors, they are much sturdier than a standard office building, and its seismic robustness could be increased through several methods discussed in "Increasing Safety." (The "utility" component of RLUOB is the Central Utility Building, separated from RLUOB by about a foot.) It appears that detailed analysis would be needed to determine the seismic performance of RLUOB as is, whether a collapse of the office would breach the laboratory ceiling, what reinforcements would be suitable, how effective they would be, and what they would cost.
2. Non-governmental organizations and members of the public might be concerned about any efforts to relax standards pertaining to nuclear facilities. Safety and other standards exist for a reason; would relaxing them add risk, and if so, by how much? Some might oppose introducing more than 26 g of WGPu into RLUOB on grounds that so doing could pose a direct threat to the surrounding area in the event of an earthquake that collapsed the building.
3. Relaxing standards for one building could set a precedent for so doing for other nuclear weapons buildings or other projects more generally.
4. Some might fear that this project could open the way for other plutonium projects at Los Alamos. As discussed in Option 12, the laboratory is considering a modular option, with a tunnel built to connect PF-4 and RLUOB and reinforced-concrete underground rooms or "modules" built off the tunnel for high-MAR plutonium operations. In this view, using trucks to transport samples between PF-4 and RLUOB would forestall or delay the modular option. Others might favor the tunnel in part because it would facilitate the modular option.
5. Some may fear that NNSA might not do an adequate EIS. One of the tests for a Categorical Exclusion in DOE regulations (10 CFR 1021.410) is

   > (3) The proposal has not been segmented to meet the definition of a categorical exclusion. Segmentation can occur when a proposal is broken down into small parts in order to avoid the appearance of significance of the total action. The scope of a proposal must include the consideration of connected and cumulative actions, that is, the proposal is not connected to other actions with potentially significant impacts (40 CFR 1508.25(a)(1)), is not related to other actions with individually insignificant but cumulatively significant impacts (40 CFR 1508.27(b)(7)), and is not precluded by 40 CFR 1506.1 or § 1021.211 of this part concerning limitations on actions during EIS preparation.

   Similarly, CEQ regulations (40 CFR 1508.7) define "cumulative impact" as follows:

> "Cumulative impact" is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.

An EIS does not meet regulatory requirements if it avoids considering all reasonable alternatives, or if only a segment of a proposed action is analyzed, or if the cumulative impacts of multiple actions are not taken into account. "Up-equipping" RLUOB (adding equipment so it can handle more AC/MC to support pit production), building a tunnel to connect RLUOB and PF-4, building one module, building a second module, and building additional modules could easily be segmented. While the modules would be HC-2, and thus significant by themselves, up-equipping RLUOB and building a tunnel to connect it to PF-4 might be seen as "small" actions that would not appear significant. But the cumulative impact of those small actions plus modules would be much larger than just an up-equipped RLUOB plus a tunnel. Further, since there is a possibility of building modules given that the FY2014 National Defense Authorization Act authorized NNSA to spend funds on a modular building strategy, once certain conditions have been met, the EIS would need to analyze the impact of that alternative, including the entire suite of projects involved (such as the tunnel), before committing to any of them.

6. RLUOB, as currently planned, would dedicate a substantial amount of laboratory space to unclassified research on plutonium. This research could explore such areas as basic properties, nuclear forensics, nuclear power plants, and Pu-238. The space would be open to individuals without clearances. Providing space for postdoctoral fellows to conduct plutonium research would benefit LANL by attracting potential recruits to the lab, and discoveries made by these individuals or foreign nationals could benefit the weapons program. If RLUOB is permitted to have 1,000 g of WGPu in order to support the weapons program, most if not all of the unclassified laboratory space would be converted to classified space.

Since the laboratory space at RLUOB could perform AC and some MC work, but questions remain about seismic robustness in light of the possible collapse of the office floors, would it be possible to …

Option 11. Build a Copy of RLUOB Minus the Office, with Regulatory Relief, for Analytical Chemistry, with PF-4 Conducting the Balance of Pit Work

A concern with RLUOB, even with regulatory relief, is that the office component could collapse in an earthquake and breach the ceiling of the laboratory, releasing plutonium. A simple way to avoid that problem would be to build an "RLB," or Radiological Laboratory Building. Construction of RLUOB was completed in FY2010. The FY2012 NNSA budget request shows the total project cost of the facility as $164.0 million, including the office floors and the Central Utility Building (CUB), and another $199.4 million for installing equipment.[125] An RLB built as a copy of the laboratory space in RLUOB should cost considerably less (when adjusted for

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[125] U.S. Department of Energy. Office of Chief Financial Officer, *FY 2012 Congressional Budget Request*, Volume 1, National Nuclear Security Administration, DOE/CF-0057, February 2011, p. 227. The FY2012 request document is the most recent with total funding for RLUOB; neither the FY2013 nor the FY2014 NNSA congressional budget request documents contained that information. The Central Utility Building is a part of RLUOB and was intended to provide utility support to RLUOB and to CMRR-NF. It is physically separated from RLUOB by about a foot.

inflation) than RLUOB because the office structure would be eliminated, the plans for the lab space already exist, and lessons learned from RLUOB could be applied to facilitate construction. The CUB was intended to provide utilities to CMRR-NF, a larger building than RLUOB, as well as to RLUOB; CUB should thus have the capacity to support most of RLB's needs. If RLB were built as a copy of the basement and laboratory floor of RLUOB, it would need regulatory relief in order to hold enough plutonium to do the AC/MC work needed to support 80 ppy.

Regulatory relief would be unnecessary if RLB were to be built as an HC-3 building. However, meeting HC-3 standards would result in a substantial cost increase for paperwork, studies, and testing to certify the same equipment (fans, filters, fire suppression equipment, etc.) because the standards would be much higher. Another issue for RLB is that that structure would probably be sited in the location previously planned for CMRR-NF. In that case, building it there could preclude modules. Some would see that as a plus, others as a minus.

If regulatory relief for RLB were not forthcoming, or if an HC-3 RLB proved too costly for a building holding 1 kg of WGPu, or if RLB plus PF-4 did not provide enough space or MAR for all the pit work that would be needed to produce 80 ppy, another approach would be to …

Option 12. Build Modules Connected to PF-4 for High-MAR Plutonium Work

Los Alamos's preferred approach to the plutonium strategy is a three-part plan: maximize use of RLUOB, repurpose space in PF-4, and build modules linked to PF-4. This section discusses the modules and their pros and cons.

In concept, the modules would be like "RLB" in that they would be seismically-reinforced laboratory-only space. There would be key differences: the modules would be completely buried instead of mostly aboveground, would be designed and built as HC-2, would do high-MAR work instead of AC/MC, and each would be for a single purpose.

PF-4 is built as modules under one roof. They all utilize the infrastructure and supporting systems of PF-4, such as shipping, receiving, waste management, nondestructive assay, entry control, and security, but are designed so plutonium accidentally released in one room would be contained within that room. The LANL approach envisions building a tunnel from PF-4 to RLUOB with modules connected to the tunnel. The first modules would be for tasks involving large amounts of MAR: Pu-238 processing, a pit foundry, or processing plutonium dissolved in acid. Moving these tasks out of PF-4 would remove about 70 percent of the MAR in PF-4.[126] So doing would make more MAR available for other tasks involving MAR while staying within the limit prescribed for PF-4.

A key lesson learned from seismic simulation studies of PF-4 and RLUOB is that the larger the dimensions of the structure, the greater the seismic loads imparted to equipment anchored to the floor. As currently envisioned, modules, at 3,000 to 5,000 square feet, would be smaller than RLUOB (19,500 sf) and PF-4 (60,000 sf). They would be lower in height and narrower than those buildings and made of thick concrete heavily reinforced with rebar. They would be constructed in the 3-acre excavated area between RLUOB and PF-4 that was dug out for CMRR-NF (see **Figure 4**) and then buried with a special concrete that matches the density of the rock (called tuff) on which the modules would sit. By matching the density of the tuff, a seismic wave would pass through the concrete more smoothly, reducing its impact on the modules. Surrounding the

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[126] Kniss and Kornreich, "A Proposal for an Enduring Plutonium Infrastructure," p. 4.

structure with concrete would reinforce the walls. A buried structure has the added advantages of minimizing concerns regarding securely transporting plutonium between the modules, PF-4, and RLUOB, and avoiding such natural phenomena as fires and high winds.

Los Alamos recognizes that the "big box" approach—building a single large building like PF-4 or CMRR-NF—no longer appears politically and fiscally sustainable over the decades required to plan and build such a facility. As Senator Lamar Alexander said, "if the NNSA does not find a more effective [way] to deal with design of these large multi-billion dollar facilities that NNSA builds it's going to lose congressional support for those facilities."[127] Part of the problem is that a big box design is typically too ambitious and too cautious at the same time. It is too ambitious because when there is an opportunity to build a plutonium facility only once in 25 or 50 years, there is a tendency for the design to include everything that might possibly be needed over the building's life. It is too cautious because it must comply with a vast and growing body of regulations, often of increasing specificity. Meeting goals and requirements simultaneously is difficult, a difficulty compounded because uncertainties concerning goals and requirements increase the further out projections are made.

Accordingly, in this view, a new approach is needed. Los Alamos argues that modular construction offers numerous advantages. Since modules would be much smaller than large buildings, they could be built faster and at lower cost. Since each module would house a single operation, safety planning could be specific to each module instead of, as at present, accommodating the highest-risk type and quantity of material. Modules could be built as needed, rather than having to incorporate in a single building all the functions that it might need to perform at some point during its service life. The modular approach, it is argued, would permit a steady level of funding rather than the large spikes of funding involved with construction of a large building like CMRR-NF, making the funding profile more predictable for Congress and the Administration. Design and construction of each module would benefit from lessons learned from previous modules, reducing cost. Reducing MAR in PF-4 would extend that building's service life if future regulations were to reduce its permitted MAR, as was the case with CMR.

While the modular building strategy is, at this point, only a concept, it is gathering steam. Preliminary design work, cost estimates, and schedule estimates are underway and, as noted, the FY2014 National Defense Authorization Act authorizes this strategy. Nonetheless, several questions bear on its desirability:

- Is it needed? Could PF-4 plus RLUOB with regulatory relief produce 80 ppy and perform other plutonium tasks without the modules at acceptable risk levels?
- Would moving Pu-238 work to INL or SRS obviate the need for modules? Pu-238 accounts for 40 percent of MAR permitted for PF-4, and 8,000 sf of lab space. Would moving it out free enough MAR and space for PF-4, especially in conjunction with RLUOB, to do the added pit work needed to reach 80 ppy? Is there a need to move 70 percent of the MAR out of PF-4?
- Is it needed now? Future requirements for plutonium work might require added space. But NNSA projects that the TA-55 Reinvestment Project will extend the service life of PF-4 to 2039, for a total of 61 years, a projection not contingent on

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[127] U.S. Congress. Senate. Committee on Appropriations. Subcommittee on Energy and Water Development. FY2014 National Nuclear Security Administration Budget, hearing, April 24, 2013. (No public transcript is available.)

building modules. If RLUOB has a 50-year service life, it could remain operational until 2059. Can a decision on modules be delayed?

- While modules might save money by drawing on PF-4 infrastructure, they would be HC-2 buildings. As such, they would need their own ventilation, continuous power, fire suppression equipment, emergency access, and the like, all of which would be safety class and thus very expensive. What would the modules cost?
- NNSA has experienced delays and cost growth in many of its larger nuclear construction projects. The modular approach offers features that could help avoid these problems, such as a smaller scale, application of lessons learned from building previous modules, and construction of each module to accommodate only the purpose for which it is built. But the modules would be separate new facilities. Given NNSA's track record, can Congress have confidence that the modules would not encounter cost and schedule problems?
- Two arguments for modules are that they would make the funding profile more predictable and that modules could be built as needed. But if the schedule for module construction cannot be predicted, neither can the funding profile.
- Compared to modules, would it be faster and less costly to upgrade PF-4, use RLUOB for AC, and move Pu-238 out of PF-4?
- MAR limits in PF-4 are conservatively set. Mitigation measures, discussed next, would further increase the difference between the frequency of the DBE and the frequency of an accident resulting from that earthquake. Could MAR limits be raised without serious adverse potential consequences? Would that reduce the need to build modules as a way of reducing MAR in PF-4?

Making RLUOB/PF-4 Options Safer and More Efficient

Safety and efficiency are not static. Both can be improved. "Improved safety," as used here, means reducing the risk of a design basis accident (DBA). (Other types of safety, such as reducing the number of falls, are dealt with on a routine basis and are not considered here.) "Improved efficiency," as used here, means increasing capacity (number of ppy). This analysis focuses on Option 10, as this analysis is most applicable to that option; the analysis would also apply to Options 8, 9, and 11. Regarding Option 1, work is already underway on improved safety through TRP. Improving safety and efficiency are not relevant to Options 2, 3, 4, and 12 because, as new buildings, they would be designed and built to comply with the most modern safety standards. Improving safety and efficiency to a significant degree is not practical for Option 5 because CMR is so vulnerable to an earthquake. This analysis is also not relevant to Options 6 and 7, which involve modifying existing buildings at sites other than LANL.

Increasing Safety

How could the risk of a DBA be minimized? A DBA must be prepared for buildings that are HC-3 and higher, not Radiological Facilities. However, if RLUOB held 1 kg of WGPu, whether as an HC-3 building or a Radiological Facility with modifications and regulatory relief, it would be beneficial to construct a DBA in order to analyze the sequence of events leading to the DBA. *The key point is that the DBA sequence is not inevitable;* a DBA would show many points at which the accident sequence could be interrupted. Taking actions to interrupt that sequence would greatly reduce the probability that the entire DBA sequence would occur, thereby reducing the likelihood that anyone would receive any dose and reducing the dose should the DBA occur.

PF-4, as an HC-2 building, has a DBA. NNSA is conducting work at PF-4 through TRP to reduce the probability and consequences of a DBA. A DBA for RLUOB might specify an amount of Pu-239E in the building and include the following sequence: an earthquake that collapsed the building, followed by a fire that converted plutonium at risk to plutonium oxide particles that the fire lofted into the air, resulting in a dose to personnel beyond DOE guidelines. This section discusses possible ways to mitigate the risk of each event in the DBA sequence.

Reducing the Risk of Building Collapse

LANL did not study the probability that RLUOB could survive an earthquake of given magnitude because that analysis is not required for a Radiological Facility. However, as discussed in **Appendix E**, RLUOB was designed to survive the 1995 design basis earthquake, which was appropriate for an HC-3 building. Since then, the DBE has been increased in severity. If RLUOB is to be used for 1,000 g of WGPu, whether upgraded to an HC-3 building or not, it may prove desirable to strengthen it. This could be done in several ways; note that these measures could reduce the consequences as well as probability of building collapse.

The Stanford Linear Accelerator Center (SLAC) in California has facilities built near the San Andreas Fault, so seismic resistance is a design consideration. Matthew Wrona, Director of the Facilities Division at SLAC, noted that most buildings typically are designed to resist vertical loads, as they must bear the gravity loads. An earthquake, however, imposes lateral (horizontal) loads as well as vertical loads, and seismic resistance requires resistance to both. Wrona pointed to several methods to strengthen an existing building to resist seismic loads:

- Strengthen connections between columns and (horizontal) beams, such as by using welded moment resisting connections, to increase lateral load resistance of the building.
- Install diagonal bracing in load bearing exterior and interior walls.
- Add steel plates to the inside or outside of a building to stiffen it against lateral loads.
- Use buttresses anchored to the ground and to the outside of the building. Buttresses would resist lateral loads.
- Strengthen floor diaphragms to distribute lateral loads to supporting walls.[128]

SLAC has used several of these techniques to brace office buildings, as **Figure 13** shows.

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[128] Telephone conversation, September 20, 2013. Wrona states that a moment resisting connection is a "stiffened connection that would resist rotation in addition to transmitting loads from horizontal beams/girders to vertical columns and from columns to the foundations," and a floor diaphragm is a "continuous floor or roof, that would distribute the horizontal seismic loads to the supporting walls." Emails, September 24 and 26, 2013.

Figure 13. **Seismic Bracing of Office Buildings**

At the Stanford Linear Accelerator Center

Source: Photographs by JoAnn Polizzi, Stanford Linear Accelerator Center, October 21, 2013.

Notes: Clockwise from upper left: 1: buttresses attached to an external brace (the four metal squares); 2: a buttress anchored to the ground; 3: another type of buttress and external brace; 4: an external brace without buttresses.

Figure 14. Notre Dame Cathedral

Source: CRS.

Notes: Construction on this cathedral in Paris began in 1163.

As **Figure 14** shows, buttresses have been used for many centuries to support buildings. Another strengthening method is base isolation technology, as shown in **Figure 15**.

A LANL structural engineer provided the following comment:

> Any number of techniques could be used to strengthen RLUOB to resist higher seismic forces. External bracing could be used, and the use of this technique at SLAC is a good example. Other possibilities may be to strengthen the internal steel-to-steel connections or the installation of internal shear walls and/or bracing. Base isolation has been applied to some structures to reduce the seismic loads that they would see during an earthquake. It might be applicable to RLUOB, either at the building foundation or at the junction between the concrete structure and the steel office structure above it. Another option may be to install internal dampers that absorb the energy of seismic motion that reduce structure displacements and accelerations which lead to reduced seismic loads. The point is that there are effective upgrades that could be implemented to improve seismic resistance. To choose the most effective set of upgrades, seismic/structural engineers need to complete a thorough analysis of the existing facility with an understanding of the performance required and using the appropriate ground motion in conjunction with applicable federal, state, and local seismic codes.[129]

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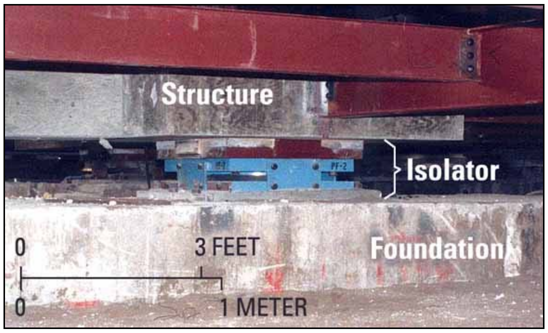
[129] Personal correspondence, Larry Goen, LANL Seismic Program Manager, November 8, 2013.

Figure 15. A Base-Isolation System



Source: Mehmet Celebi and Robert Page, "Monitoring Earthquake Shaking in Federal Buildings," U.S. Geological Survey Fact Sheet 2005-3052.

Notes: "Base-isolation systems dampen the shaking energy fed into the structure through its foundation, thus reducing the likelihood of damage." This system was installed in the Court of Appeals Building in San Francisco.

NNSA has undertaken several projects to reduce the risk of building collapse for PF-4. Its TRP is intended to add about 25 years of expected useful life. TRP has multiple projects, including seismic upgrades to glovebox stands, as shown in **Figure 16**.[130] This upgrade is intended to prevent the gloveboxes from falling over during an earthquake and releasing plutonium. NNSA undertook many other projects in conjunction with its June 2011 Seismic Justification for Continued Operation. It noted that repairing one building feature (drag strut) reduced the dose from 2,100 rem for a once in 5,000 year event to 143 to 278 rem for a once in 2,000 year event. NNSA took many other actions to address seismic hazards, including "strengthen[ing] the roof, thereby addressing the most significant known weakness—a building collapse failure mode," and "brac[ing] ventilation room columns, addressing the next most significant known weakness."[131] Additional repairs, NNSA estimated, could reduce the dose to an MOI to less than 25 rem.[132]

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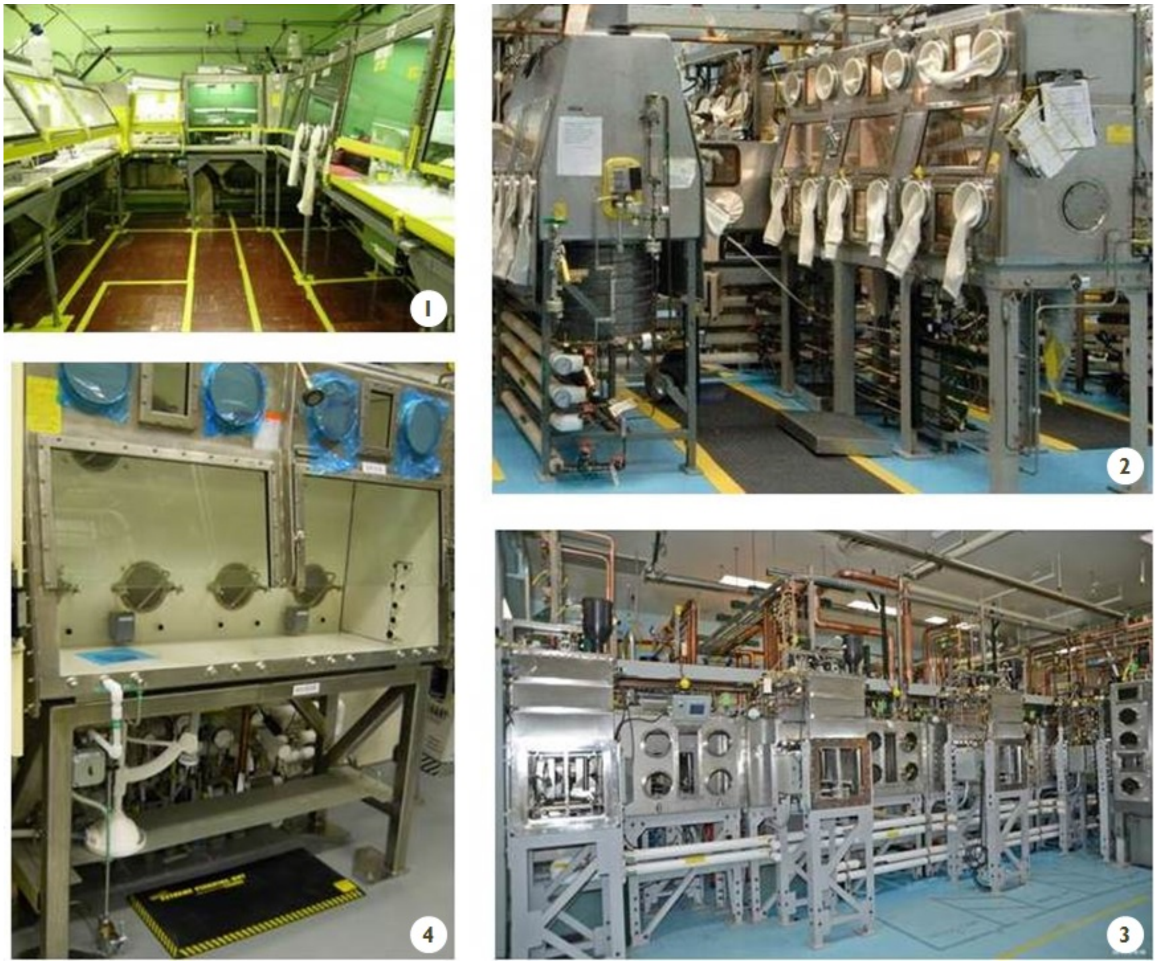
[130] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2014 Congressional Budget Request,* DOE/CF-0084, April 2013, Volume 1, National Nuclear Security Administration, pp. WA-198, WA-211.

[131] Letter from Donald Cook, Deputy Administrator for Defense Programs, National Nuclear Security Administration, to Peter Winokur, Chairman, Defense Nuclear Facilities Safety Board, January 30, 2012, Enclosure 2, pp. 2-3.

[132] Ibid., Enclosure 1, p. 1.

Figure 16. Progressive Strengthening of Gloveboxes and Open-Front Hoods



Source: Photos by Los Alamos National Laboratory.

Notes: Workers in PF-4 use gloveboxes (GBs) to work on plutonium in an inert atmosphere, often argon gas, because molten plutonium or plutonium shavings can oxidize rapidly (burn) when exposed to air. A major concern in working with plutonium is that GBs could fall over in an earthquake. If that happened, the GBs could break, exposing molten plutonium or plutonium shavings to air, resulting in particles of plutonium oxide that fire could loft into the atmosphere. Similarly, a fire would cause the liquid in a plutonium-acid solution (whether in a GB or an open-front hood) to boil, leaving plutonium that would form tiny particles of plutonium oxide. To reduce the likelihood of this problem, GBs and hoods have, over time, been strengthened and anchored more strongly to the floor.

These photos show this progression. Clockwise, starting with upper left photo: (1) A GB in CMR. The legs are spindly and minimally anchored to the floor. They do little more than support the GBs. Care would be needed in anchoring GBs more strongly in CMR because the floor is only two inches thick in some areas. Anchors in those areas could weaken the floor, possibly increasing the risk of GB collapse in an earthquake. (2) Two types of GBs in PF-4. The ones on the left were brought into PF-4 when it opened and were moved in from a 1950s building. All such GBs have been removed from service in PF-4. The GBs on the right are typical of those currently in use in PF-4. Note the stronger legs, the stronger platform on which the GBs sit, and the absence of diagonal bars for cross-bracing. (3) GBs in PF-4 with added strengthening. The GB supports have extensive cross-bracing and use much more steel. This type of bracing is used for GBs that contain large quantities of plutonium, and is typical of new GBs installed in PF-4. (4) An open-front hood in RLUOB. The legs are much stronger than those supporting older PF-4 GBs, have cross-bracing, and are anchored with large steel plates bolted to the floor. The GBs in (3) and the hood in (4) are examples of the most current seismic strengthening and are similar in their resistance to collapse.

Reducing the Risk of Fire

A second part of the DBA is that building collapse is followed by a fire that engulfs several rooms of the laboratory space. Various methods could be used. The simplest is to reduce the amount of combustible material in the building. While this seems self-evident, Los Alamos removed about 20 tons of combustible material from PF-4 between 2010 and 2012.[133] Other steps taken in PF-4 included implementing a program to control ignition sources, repairing the main fire wall, addressing other structural issues, and increasing the capability of fire suppression systems. NNSA calculated that these and other measures to reduce the consequences of a post-earthquake fire at PF-4 would reduce the dose from this accident from 2,860 rem as of December 2008 to 23 rem as of June 2012 and well under 1 rem by September 2020.[134] (This dose is for an MOI.)[135] Similar measures should reduce the risk of a fire in RLUOB.

Reducing the Amount of Plutonium Consumed in a Fire

A fire would not loft a plutonium ingot into the air because plutonium melts at a high temperature, 1,183 degrees F, and a fire would likely form a layer of plutonium oxide on the surface of the ingot that would keep oxygen from reaching the interior. To be lofted into the air in a form in which it can disperse and be inhaled, it must be converted to tiny (respirable) particles of plutonium oxide. Such particles can be formed if a fire reaches molten plutonium, plutonium shavings, or plutonium dissolved in acid; the latter would readily combine with oxygen if the acid boiled away.[136]

NNSA has taken many steps to reduce the amount of plutonium consumed in a fire in PF-4. These include installation and use of fire-resistant safes and containers for storing nuclear material, procurement of containers for special nuclear materials that "are designed to provide increased assurance of confinement in a seismically-initiated fire when stored in environments not susceptible to direct flame impingement," "replac[ing] vault sprinkler heads with lower-actuation-temperature heads that will respond sooner and limit the development of a vault fire," and "impos[ing] restrictive material-at-risk limits to reduce the amount of plutonium that could be released in an accident." Another step is making sturdier gloveboxes and anchoring them more strongly to the floor so as to reduce the risk that they would topple over in an earthquake, releasing plutonium. **Figure 16** shows the progressive strengthening of gloveboxes. Future plans include installation of fire suppression equipment in gloveboxes and improving fire barriers.[137]

There are many potential ways to reduce MAR—actually, MAR per pit—that would reduce the amount of plutonium that a fire in RLUOB would consume. Since many AC techniques date back to the Cold War, it may be possible to update them to take advantage of current technologies and requirements in order to reduce MAR. Possibilities include:[138]

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[133] Ibid., Enclosure 2, p. 1.

[134] Ibid., Enclosure 1, p. 5, and Enclosure 2, pp. 1-2.

[135] Ibid., Enclosure 3 p. 3.

[136] Plutonium shavings have a large surface area per unit mass. If exposed to air, they would burn easily. Molten plutonium is so hot that it would have absorbed most of the energy needed for it to burn. The large surface area of molten plutonium spilled out of a glovebox would also be exposed to air, further increasing its susceptibility to fire.

[137] Letter from Donald Cook to Peter Winokur, January 30, 2012, Enclosure 2, pp. 1-3, and Enclosure 3, p. 3.

[138] Most of the information in this section is based on telephone conversations with Los Alamos National Laboratory staff, June-August 2013.

- Take fewer samples per pit. AC at present is performed much as it has been since the Cold War, as discussed in "The Pit Production Process." Improved analytic instruments and improved understanding of plutonium and its impurities might permit reducing the number of samples. It may also be the case that these numbers reflect an excess of caution and an abundance of resources characteristic of the nuclear weapons program during the Cold War. Taking fewer samples per pit would reduce the sample prep workload in PF-4, the AC workload in RLUOB, and the workforce and floor space required in both buildings.
- Perform fewer analyses per sample. Sometimes multiple analyses are performed to reduce the risk of missing needed information in process control. Reducing redundant analyses should have similar benefits as reducing the number of samples per pit.
- Accept less precision of measurement. While an AC procedure that originated decades ago might require precision to within plus or minus 1 percent, precision to within plus or minus 5 or 10 percent might suffice. That could permit faster sample processing, reducing MAR per pit. In addition, relaxing the requirement would, in some cases, permit one analysis technique to perform several types of measurements, while more precise techniques might require a piece of equipment for each measurement type. Using fewer pieces of equipment would also free up floor space in PF-4 or RLUOB.
- Devise ways to reduce the time that various AC techniques require. Faster processing would reduce the number of hours that material is at risk for each pit, and would permit more work to be done in a given amount of floor space, perhaps with fewer workers, reducing aggregate worker exposure to radiation.
- By reducing MAR per pit, RLUOB could support AC for a higher production rate, or could conduct AC for a given number of pits under a lower MAR ceiling.

Minimizing the Amount of Plutonium Oxide Lofted into the Air

Even if an earthquake collapsed the building and a fire converted some plutonium to plutonium oxide particles, that material would not pose a threat unless it escaped from the building and was lofted into the air by the fire. Not all the plutonium at risk in RLUOB would leak into the atmosphere. The first floor of the building is laboratory space, but there is a basement below it and three floors above it. In an earthquake that collapsed the entire building, the first floor would collapse into the basement and the upper floors would collapse onto the laboratory space, sealing in some plutonium. Other steps might further reduce leakage. As a possible example, the foam used to extinguish aircraft fires, if used in a fire in RLUOB, might trap plutonium. A careful analysis of such techniques would be required to determine their efficacy and whether they would create criticality problems. Development of such techniques would be of value for RLUOB, PF-4, and other buildings containing nuclear materials.

Dose Would Be Very Low Even Without Mitigation

Even in a worst-case accident, the dose from plutonium released from RLUOB would be very low. NNSA, in discussing PF-4 stated, "Unmitigated/mitigated radiation doses were 7,250 rem/2,900 rem, based on an accident scenario involving 5MT [metric tons, i.e., 5,000 kg] of one plutonium material form [molten WGPu], an unconstrained full-floor fire, and an assumed 40 percent leak path factor [i.e., 40 percent of plutonium is released into the air]."[139] (That calculation is beyond worst case, as the MAR allowance for the PF-4 main floor is 2,600 kg Pu-239E.[140] Nonetheless, it is useful for providing a baseline for calculating the dose that might result from the release of 1 kg of WGPu.) If RLUOB held 1 kg of WGPu, and if the leak path factor for this accident at RLUOB, without mitigation, were 40 percent, then the resulting dose would be 1/5,000th of 7,250 rem, or 1.45 rem. Even if the leak path factor were 100 percent, the dose would be 3.6 rem, near the bottom end of the dose range having no detectable clinical effects. (It is unclear if this dose is for MOI, CW, or others.) **Appendix B** presents another, more detailed calculation that produces even lower results for an MOI. Further, that Appendix shows that the value of "airborne release fraction" is very conservative, so that the dose could be tens or even 100 times less than shown in **Table B-1** and **Table B-2**.

Increasing Efficiency

Efficiency, in this context, refers to the efficient use of space so as to enable more pit work to be performed in PF-4 and RLUOB.

Increasing Space for Pit Production and Supporting Tasks

Producing 80 ppy would require more space for production equipment and AC. (Los Alamos has not calculated the precise amount of space required, and the requirement could change between now and 2030, when the capacity is needed.) Since pit fabrication could only be done in PF-4, more space in that building would have to be dedicated to that task. Some ways of achieving this space are straightforward:

- RLUOB could be utilized for AC and some MC.
- MC would not require much more space to support 80 rather than 30 ppy, as it is used to qualify production equipment and processes and to help solve production problems. However, some MC, such as the gas gun, might be moved into RLUOB.
- Some space could be repurposed; other space could be made available by moving Pu-238 out of PF-4.

Increasing Efficient Utilization of Space

Space in PF-4 could be utilized more efficiently, which would have the same effect as increasing floor space.

- PF-4 and RLUOB could operate on two shifts per day. This would be much less costly, much more feasible, and much quicker than building new plutonium buildings, and would have much less environmental impact. LANL estimates that using two shifts per day rather than one increases productivity by a factor of 1.6. Multiple shifts are not new to the nuclear weapons complex; Rocky Flats Plant

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[139] Letter from Donald Cook, Deputy Administrator for Defense Programs, National Nuclear Security Administration, to Peter Winokur, Chairman, Defense Nuclear Facilities Safety Board, January 30, 2012, Enclosure 2, p. 1, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Letters/2012/ltr_2012130_18446_0.pdf.

[140] Information provided by Los Alamos National Laboratory, email, January 6, 2014.

sometimes operated with three shifts a day, and SRS currently conducts some operations that way.

- As noted earlier, the vault in PF-4 for holding plutonium is being cleaned out, with excess material sent to WIPP for final disposition. Excess material that may need to be retrieved could be sent to other sites.
- It may be possible to design equipment to minimize space requirements. Space efficiency was not a major consideration when PF-4 equipment was originally designed; focusing on this goal and bringing modern technology to bear might permit more work to be done in a given space. Having more plutonium in a room would increase the dose to workers unless shielding is increased; this would be a much greater concern in PF-4, where work with kilogram quantities of plutonium is conducted, than in RLUOB, which would use very small samples.

Gathering Information on Various Options

In order to examine the costs, risks, and benefits of the options discussed in this report, Congress would need further information. To gather it, Congress could direct NNSA to conduct several studies, including the following:

Study of potential PF-4/RLUOB production capacity: Since it is unlikely that new plutonium buildings (especially large ones) will be built for many years, PF-4 and RLUOB have value beyond their cost. Many measures could increase capacity, such as moving Pu-238 out of PF-4, repurposing space in PF-4, and permitting RLUOB to perform all AC. Congress could direct NNSA to study whether some combination of such measures would enable production of 80 ppy while maintaining other essential plutonium missions in PF-4, and the number of ppy RLUOB and PF-4 could produce if more or less than 80.

Study of repurposing PF-4 space: Los Alamos plans to repurpose some space in PF-4. Could enough space be made available for pit production and support without disrupting other critical missions in the building? If such disruption was required for pit production, could other missions be done in existing facilities elsewhere in the nuclear weapons complex, or would new facilities have to be built? If new facilities were required, what would they cost and how long would they take to build, and what would happen to the mission before they were completed?

Study of the feasibility and cost of converting RLUOB to HC-3: RLUOB was built but not certified to HC-3 standards; it is sometimes called an "HC-3-like" building. In order to hold 1,000 g of WGPu while complying with regulations, it would have to be certified to HC-3. This would involve many actions. Many would be studies, but some of them could lead to physical changes to the building, such as seismic bracing or installation of equipment. It is not clear what physical work would be required. A "study of studies" would help determine if conversion would be feasible, and if so at what cost.

Study of adverse consequences of allowing RLUOB to operate as is but with 1,000 g WGPu: Converting a Radiological Facility to HC-3 would entail costs, yet the dose resulting from an earthquake that collapsed RLUOB would be far below the guidelines set by DOE, as **Appendix B** shows. Congress could direct an independent organization to study the adverse consequences of using RLUOB for 1,000 g of WGPu as is, i.e., with AC equipment installed but no steps to convert the building to HC-3. If it is determined that RLUOB as is would not provide adequate safety with 1,000 g WGPu, a related study could examine if there are additional steps short of full conversion to HC-3 that would provide adequate safety, and what they would cost.

Study of having LLNL, SRS, or both perform some AC to support pit production: LLNL and SRS have infrastructure to perform AC to support pit production, though beyond some level of capacity they would need to upgrade equipment and hire additional staff. There would be benefit from dispersing AC expertise, capacity, and work to other sites in the nuclear weapons complex, but also benefit from concentrating them at LANL, the plutonium center of the nuclear weapons complex. It seems unlikely that a site other than LANL would perform all AC to support pit production. At issue: Should one or more sites other than LANL perform some AC to support pit production? If so, how much capacity should be dispersed to other sites? Which site or sites should be chosen? What would it cost to upgrade the site or sites for that capacity?

Study of Pu-238 options: Pu-238 activities are costly given the high level of radioactivity of that material. Pu-238 work could be moved to INL, SRS, a module at LANL, or perhaps other sites. DOE's Office of Nuclear Energy prepared a study on this topic. However, that study did not consider the costs and benefits to the weapons program of moving Pu-238 out of PF-4; those costs and benefits might change the calculus of that move. Specifically, if moving Pu-238 to another site made a major contribution toward permitting production of 80 ppy without building new buildings, the value to the weapons program would be significant , and reducing MAR in PF-4 could help extend its service life. On the other hand, while DOE has estimated the cost of the INL or SRS options for Pu-238 to be several hundred million dollars, other costs would be involved, as well as temporary disruption of the Pu-238 program. Congress could direct NNSA to contract with an independent organization to study these costs and benefits.

Study of cost implications of the regulatory system: A Radiological Facility is able to hold 38.6 g Pu-239E (26 g WGPu). As shown by RLUOB, such facilities can be affordable and can be built. In contrast, the history of the past quarter-century, as discussed in "A Sisyphean History: Failed Efforts to Construct a Building to Restore Pit Production," has been that a facility intended to hold more than 26 g WGPu has seen cost and schedule escalate to the point where it cannot be acquired. These efforts have resulted in the expenditure of billions of dollars with the net result of canceled programs, unusable buildings that had to be demolished, and continued operations in "decrepit" facilities. Congress could task NNSA to report on cost implications of the current regulatory system governing nuclear facilities, focusing on tradeoffs between cost and risk.

Concluding Observations

Long-term planning is difficult for all parties concerned. Delays and cost growth by NNSA on its major facilities reduce confidence in NNSA's cost and schedule projections, making it difficult for Congress and the Administration to budget for these facilities. NNSA sources say that congressional budgeting outside the regular budget process, such as sequesters and short-term continuing resolutions, and withdrawal of congressional support, such as the termination of MPF, make it difficult for NNSA to plan. Changes in Administration planning, such as the deferral of CMRR-NF, make it difficult for Congress and NNSA to plan.

Long-term planning for pit production has proven particularly difficult. NNSA provides plans going out 10 to 20 years. However, these plans have often been stretched out, canceled, or modified substantially. Pit production at Rocky Flats Plant halted in 1989, yet LANL did not produce its first war reserve pits until 2007, NNSA has not needed to expand its small capacity, and there is still no plan for larger-scale pit production. Planning for MPF began in 2002, and

Congress canceled it in 2005, followed by planning for CMRR, with the Nuclear Facility deferred "for at least five years" by the Administration in its FY2013 budget request. Similar delays have occurred with other nuclear weapons complex construction projects and with LEPs. While organizations need long-term plans as general guides to future plans, this history raises questions about the value of such planning.

Requirements for pit production capacity have been fluid, reducing their credibility. The options studied for MPF in a 2003 EIS were between 125 and 450 ppy. Even if pits had a service life of 45 years, as was thought at the time, a 450-ppy capacity would support a stockpile of some 20,000 weapons, far more than the stockpile had. Then, the interim capacity at LANL was 10 ppy, with a goal of 30 ppy by 2021 and a requirement of 50-80 ppy by around 2030. Yet this latter requirement was not based on an analysis of weapons, targets, and scenarios, but on what NNSA estimated that Los Alamos could produce with PF-4 and CMRR-NF. Despite the deferral of CMRR-NF, and congressional authorization for NNSA to pursue a modular strategy as an alternative to that facility, the requirement for 50-80 ppy remains, and it is unclear if the number needed is 50 or 80. At the same time, steady increases in estimates of pit life, steady reductions in numbers of weapons, and the possibility of reusing pits from retired weapons may reduce the required capacity. As a consequence, it is hard to know what capacity is needed, and thus what new facilities or modifications to existing ones are needed.

Differing time horizons between Congress and NNSA, and between political and technical imperatives, cause problems. Congress and the Administration, on the one hand, and DOE, NNSA, the labs, and the plants, on the other, work on very different timescales. It takes well over a decade, at best, for NNSA to bring a major nuclear facility project from initial approval to design, construction, and operation. In contrast, Congress and the Administration have changed course often on a plutonium strategy, sometimes from one year to the next. The more time from start to finish of a project, the more chance there is for intervening events to alter plans. Thus it would be to NNSA's advantage to drastically shorten the time from start to finish of a project. A construction cycle of a decade or more (or 24 years and counting in the case of a new plutonium facility) faces great difficulty when its funding hinges on a political cycle of one or a few years.

For a successful plutonium strategy, Congress would find unacceptable management that allows costs to grow immensely, ten-fold in some cases, or that allows multi-year delays. At the same time, Congress and the Administration cannot expect a project to be completed in a couple of years. Analysis of alternatives, site surveys, compliance with NEPA requirements, planning, contracting, and construction typically take years.

Thus, time is of the essence and delay is the enemy. This is a problem for Congress, the Administration, DOD, NNSA, the nuclear weapons complex, and the nation. Is there is a meeting-ground between the political and technical worlds? Can NNSA define the need for a major nuclear facility construction project, then quickly design it, comply with various federal, state, and local regulations, and build it? How could NNSA expedite the process? Can it avoid cost growth, delay, and mission creep? Conversely, once a project is defined, can Congress and the Administration commit to it on a longer-term basis?

NNSA would need to gain the confidence of Congress in its ability to manage major construction projects. The capacity range studied for MPF implied the nominal ability to support a stockpile far larger than the then-current and likely future stockpile. CMRR-NF experienced a several-fold increase in estimated cost and years of schedule slippage. Failing to provide a realistic estimate of required capacity or to stay remotely close to cost and schedule estimates had consequences. Congress canceled MPF, and the Administration proposed to "defer"

CMRR-NF for "at least five years." And as noted in "Two Other Failed Attempts," two plutonium buildings were built, found to be unusable for their intended purpose, and were torn down. Congressional support for a modular strategy—yet another change in plans—increases the likelihood that the deferral of CMRR-NF will be a cancellation. Many believe that NNSA weakens its case for future projects when it releases estimates that are far in excess of a capacity that seems reasonable, or that are far below the ultimate cost and schedule, or when it changes its plans repeatedly.

There are costs and risks to doing nothing. Time spent in planning and construction for new buildings to support pit production can reduce risk, for example by studying the impact of the facility on the environment, by studying the seismicity of the construction site, by designing the facility to meet requirements (such as for Hazard Category 2 or 3), and by incorporating measures in the design to reduce dose that individuals could receive from a major accident. However, if history is a guide, it could take many years before a new facility could become operational. Until then, whether the new facility is at Los Alamos or elsewhere, CMR must be used to provide AC support for pit production in PF-4. This entails multiple risks and costs:

- CMR is at high risk of collapse in the event of even a moderate earthquake. Collapse would kill many workers in the building.
- Pit production requires much more AC than PF-4 can accommodate. Collapse of CMR, without another building to conduct AC, would—not could—disrupt pit production until another facility for AC came on line, which could take years.
- Bringing another facility online on an emergency basis would probably cost more than doing so in an orderly manner, and shortcuts taken to expedite design, siting, and construction could increase the risk of problems down the road.
- CMR has a MAR of 9 kg of Pu-239E, and all the plutonium in that facility is considered at risk because no vault or container could be counted on to survive that building's collapse. Dispersal of some of that plutonium could place collocated workers and members of the public at risk.
- Depending on specifics of the collapse (wind direction, fire, form of plutonium, amount of plutonium escaping, etc.), dispersal of the plutonium could contaminate and force the closure of parts of the laboratory, possibly for months or years. That would disrupt laboratory operations, with operations affected at random based on which areas were contaminated.
- Cleanup of a large area contaminated by plutonium would be extremely costly and time-consuming. It would be a more effective use of those funds to avoid that problem by moving operations out of CMR as soon as possible.

A facility can be safe without being compliant. As **Appendix B** shows, if RLUOB had 1 kg of WGPu, all of which was released in a DBA, the accident would result in doses well below DOE guidelines. Yet RLUOB would be in compliance with DOE regulations as a Radiological Facility only if it had less than 26 g of WGPu. As a corollary, there is a tradeoff between cost and regulatory compliance: Where is the point of diminishing returns?

Should plutonium quantity in a building be limited by MAR or dose? The regulatory system defines a building's Hazard Category by MAR. An HC-3 building can hold between 38.6 grams and 2,610 grams of Pu-239E; a Radiological Facility can hold up to 38.6 grams. The objective is safety; however, MAR is a surrogate for safety. It is simple for regulators to measure MAR. In contrast, determining dose to a collocated worker or a maximally-exposed offsite individual requires a complex analysis for each building, taking into account such factors as details of construction, measures taken to increase seismic robustness and fire suppression, and assumptions on the amount of plutonium that would be lofted into the air in an earthquake, wind speed, and wind direction. Yet it is dose, not MAR, that determines whether an individual is safe, and as shown in **Appendix B**, even with MAR of 2,610 g Pu-239E (1,750 g of WGPu) for RLUOB, the maximum permitted in an HC-3 building, dose to those individuals would be far below DOE guidelines.

Weapons and infrastructure constrain policy and strategy. Logically, these four elements should be linked, and policy and strategy should drive weapons and infrastructure. But given cancellations, multi-year schedule slippages, and major cost growth for LEPs and infrastructure facilities, even if strategy calls for having certain numbers of a certain weapon by a certain year, if an LEP is delayed by cost growth or infrastructure delays, it is the strategy that adapts.

The political system is more flexible than the regulatory system. Regulators are bound by statutes, regulations, orders, and standards, and can only determine if a plan complies with these rules without regard to cost. Standards define acceptable risk: a Radiological Facility must have less than 38.6 grams of Pu-239E; a Security Category IV facility can have up to 200 grams of pure plutonium; the DOE guideline is for an MOI to receive a dose of no more than 25 rem over 2 hours. But this system is inflexible. It does not have a way of trading risk (and the benefit of reducing it) against cost (and the benefit of reducing it). As a result, it may force the expenditure of years, and many millions of dollars, to further minimize an already-minimal risk. In order to inject cost-benefit calculations into recommendations by DNFSB, Section 3202 of H.R. 1960, the FY2014 defense authorization bill as passed by the House, required DNFSB to provide an analysis of the costs and benefits of its recommendations if requested to do so by the Secretary of Energy; in such instances, the Secretary would also be required to conduct a similar analysis. This provision, however, was not included in the final legislation, P.L. 113-66.

Even so, while the regulator can present costs and benefits, only the political system has the authority, ability, and culture to decide which tradeoffs are worth making, and to offer regulatory relief. For example, political decisions could make the difference between whether or not a RLUOB/PF-4 option is feasible. If the DOE hazard categorization standard is applied, so that RLUOB could hold only 26 grams of WGPu, then RLUOB could provide very limited AC support for pit production. If it were upgraded, the regulatory system could determine only if the upgrades would meet HC-3 requirements. In contrast, the political system could judge whether certain upgrades would reduce the risk to an MOI enough, with "enough" a matter of political judgment, and if the reduction in risk from these upgrades was worth the cost. The political system could also decide if the risk was acceptable without upgrades.

There are several potential paths forward: Several options discussed in this report have the potential to produce 80 ppy, resolve the Pu-238 issue, and permit other plutonium activities, all at relatively modest cost, in a relatively short time, with no new buildings, and with minimal environmental impact. Determining the cost, schedule, feasibility, and other characteristics of these options would require detailed study.

Appendix A. The Regulatory Structure

Laws

A dense web of "laws" (statutes, regulations, orders, standards, guides, etc.) bears on nuclear facilities and how they are to be built and operated consistent with worker safety, public health, and environmental protection. A critical point is that legislation trumps regulation: since regulations, orders, and standards derive their authority from statutes, statutes can mandate changes in them. Some of the more important laws are:

Atomic Energy Act of 1954, as amended, 42 USC 2201 et seq., is the fundamental statute setting policy for civilian and military uses of atomic energy and materials. It established the Atomic Energy Commission, which was superseded by the Energy Research and Development Administration and then by the Department of Energy.

Department of Energy Organization Act of 1977, 42 USC 7101 et seq., established the Department.

National Environmental Policy Act (NEPA) of 1970, 42 USC 4321-4347, established a national policy on the environment, mandated the preparation of environmental impact statements for certain projects and proposals that could have a significant impact on the environment, and created the Council on Environmental Quality to, among other things, review federal activities to determine their consistency with national environmental policy.

Establishment of Defense Nuclear Facilities Safety Board (DNFSB): 42 USC 2286 et seq. (P.L. 100-456, FY1989 National Defense Authorization Act) established DNFSB as an independent executive branch agency, as described in "Regulators," below. Note that the Nuclear Regulatory Commission does not regulate defense nuclear facilities.

National Nuclear Security Administration Act, 50 USC 2401 et seq. (Title XXXII of the FY2000 National Defense Authorization Act, P.L. 106-65), established NNSA as a separately organized agency within DOE responsible for, among other things, the nuclear weapons program.

Nuclear Safety Management: 10 CFR 830 sets forth requirements that "must be implemented in a manner that provides reasonable assurance of adequate protection of workers, the public, and the environment from adverse consequences, taking into account the work to be performed and the associated hazards." 10 CFR 830 lists its authority as 42 USC 2201, 42 USC 7101 et seq., and 50 USC 2401 et seq.

Nuclear Safety Analysis Report, DOE Order 5480.23, April 30, 1992. Its purpose is "to establish requirements for contractors responsible for the design, construction, operation, decontamination, or decommissioning of nuclear facilities to develop safety analyses that establish and evaluate the adequacy of the safety bases of the facilities. The Nuclear Safety Analysis Report (SAR) required by this Order documents the results of the safety analysis."

Safety Analysis Requirements for Defining Adequate Protection for the Public and Workers, Recommendation 2010-1 issued by DNFSB to the Secretary of Energy, October 29, 2010.

Regulators

The main regulators of nuclear weapons complex facilities are as follows:

The Defense Nuclear Facilities Safety Board (DNFSB) is an independent executive branch agency. Its mission, as set by legislation, is "to provide independent analysis, advice, and recommendations to the Secretary of Energy to inform the Secretary, in the role of the Secretary as operator and regulator of the defense nuclear facilities of the Department of Energy, in providing adequate protection of public health and safety at such defense nuclear facilities." It is to "review and evaluate the content and implementation of the standards relating to the design, construction, operation, and decommissioning of defense nuclear facilities of the Department of Energy … at each Department of Energy defense nuclear facility. The Board shall recommend to the Secretary of Energy those specific measures that should be adopted to ensure that public health and safety are adequately protected." Recommendations are central to DNFSB's role, especially since that agency does not issue regulations. Recommendations are not requirements, but "To date, the Secretary of Energy has accepted every Board recommendation, though three were accepted with conditions or exceptions described in the Department's acceptance letters."[141]

The DOE Office of Health, Safety and Security (HSS) integrates DOE "Headquarters-level functions for health, safety, environment, and security into one unified office. … HSS is focused on providing the Department with effective and consistent policy development, technical assistance, education and training, complex-wide independent oversight, and enforcement."[142]

The DOE Office of NEPA Policy and Compliance has as its mission "to assure that the Department's proposed actions comply with the requirements of the National Environmental Policy Act (NEPA) and related environmental review requirements … that are necessary prior to project implementation. The Office is the Departmental focal point for NEPA expertise and related activities in all program areas, covering virtually every facet of the Department's diverse and complex operations."[143]

The DOE Office of General Counsel reviews environmental impact statements and similar documents and decides whether to approve their release to the public.

NNSA Headquarters sets policy on the nuclear weapons complex, such as major construction; its programs, such as LEPs; and its operations and maintenance.

NNSA Field Offices are part of the regulatory system. Nuclear weapons complex sites are government-owned, contractor-operated. Field offices hold the contracts with the contractors and interact directly with them. For example, the Los Alamos Field Office handles day-to-day administration of the contract with the contractor, Los Alamos National Security, LLC. NNSA headquarters, in conjunction with Congress and the Administration, sets policy in such matters as how many pits to produce and what facilities to build, and the field office provides direction to the contractor for implementing policy while abiding by rules, such as for safety and security.

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[141] U.S. Defense Nuclear Facilities Safety Board, "Who We Are," http://www.dnfsb.gov/about/who-we-are, accessed February 4, 2014.

[142] U.S. Department of Energy. Office of Health, Safety and Security. "Who We Are," http://www.hss.doe.gov/whoweare.html.

[143] U.S. Department of Energy. Office of NEPA Policy and Compliance. "Mission," http://energy.gov/nepa/mission.

Appendix B. Calculation of Dose as a Function of Material At Risk

If Congress were to grant RLUOB regulatory relief so that it could hold 500 g to 1,000 g of WGPu, what risk would that pose to laboratory staff and members of the public? The following equations calculate dose resulting from a major accident that involved these quantities of plutonium, using assumptions as explained below. These calculations are only for dose, and are specific to RLUOB. They do not assess risk to individuals inside the building, nor do they assess risk from fire, earthquake, gas main explosions, and the like.

Table B-1. Sample Calculation for Deriving Dose Values for RLUOB

Factor	Maximally Exposed Offsite Individual (MOI)	Collocated Worker (CW)
MAR (g Pu-239E)	500	500
Damage Ratio, DR	1	1
Airborne Release Fraction, ARF	0.002	0.002
Respirable Fraction, RF	1	1
Leak-Path Factor, LPF	1	1
Source Term (g Pu-239E)	1.00	1.00
"Chi over Q," X/Q (s/m^3)	8.77E-05	0.0035
Breathing Rate, BR (m^3/s)	0.00033	0.00033
Specific Activity, SA (Ci/g) for Pu-239E	0.0622	0.0622
Dose Conversion Factor, DCF (rem/Ci)	5.92E+07	3.07E+07
Dose (rem)	0.107	2.21
Dose guideline (rem) per DOE regulations	5-25	100

Source: Table by Los Alamos National Laboratory, notes by CRS.

This table calculates the dose to two types of individuals in the event of a major accident. A Maximally Exposed Offsite Individual is a hypothetical person at the location nearest to the site boundary where individuals could normally be expected to be, such as on a main road or in a house. The distance from RLUOB to MOI is assumed to be 1200 meters. A Collocated Worker is an onsite worker 100 meters from the building. Dose is calculated by multiplying the factors in this table. The calculation is specific to RLUOB; values for some factors would differ for other buildings. The calculation assumes a worst-case accident, i.e., an earthquake that collapses the building, causing plutonium-containing material to spill out of containers, followed by a fire that aerosolizes the plutonium.

The factors are as follows:

Material At Risk (MAR): The amount of material, in this case plutonium, acted upon by an event. It is measured in units of grams of plutonium-239 equivalent (g Pu-239E), a standard used to compare the radioactivity of diverse materials. **Table B-1** assumes a MAR of 500 g Pu-239E; **Table B-2** uses several values of MAR.

Damage Ratio (DR): The amount of damage to the structure, with 0 being no damage and 1 being complete collapse. The calculation uses a value of 1, i.e., complete collapse of RLUOB, the worst case.

Airborne Release Fraction (ARF): The fraction of Material At Risk released into the air as a result of the event. ARF is specific to the type of material (e.g., plutonium oxide, plutonium metal, plutonium in solution). The material in this accident is assumed to be 90 percent liquid (plutonium in solution) and 10 percent waste (such as rags with plutonium oxide particles).

The value for ARF used in the calculation is 0.002, so this one value reduces dose by a factor of 500. Thus the dose resulting from an earthquake that collapsed RLUOB with 1,000g WGPu could be much higher than shown in **Table B-1** if that value is in error. A DOE handbook shows that the factor 2E-3 (i.e., 0.002) is for airborne droplets containing plutonium oxide rather than for solid plutonium oxide particles that result from the aqueous solution containing plutonium having boiled away.[144] In response to a question on the validity of using that figure in **Table B-1**, Los Alamos stated: "the ARFs and RFs are almost always VERY conservative. In most of the experiments the average value was about 1 to 2 orders of magnitude lower than the value recommended for use in Safety Analysis. So, no there is not a problem. It really more goes the other way. At each stage we used very conservative values that multiply on each other, such that the final answer in no way represents reality."[145] Consequently, the *actual* dose that would result from collapse of RLUOB with 1,000 g WGPu could be tens or even 100 times *smaller* than shown in **Table B-2**.

Respirable Fraction (RF): The fraction of the material released into the air that is of a particle size (3 microns in diameter or less for plutonium oxide) that, when inhaled, remains in the lungs. In this calculation, RF is assumed to be 1, the worst case.

Leak Path Factor (LPF): The fraction of material that escapes the building. While ARF is related to material type, LPF is related to engineered containment mechanisms, such as robust containers. In this calculation, LPF is set at 1, i.e., no containment is assumed.

Source Term (ST): The amount of material released that provides dose to individuals. It is calculated by multiplying the previous five factors together. ST is then multiplied by the following four factors to arrive at dose.

Chi over Q (χ/Q): The rate at which plutonium particles are deposited (fall to the ground). It includes such factors as wind speed, wind direction, and distance from the facility to the MOI or CW receiving the dose.

Breathing Rate (BR): The volume of air, in cubic meters per second, that an individual breathes in. This is important in calculating dose because the more air an individual breathes in, other things being constant, the higher the dose.

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[144] U.S. Department of Energy. *DOE Handbook: Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities,* Volume I - Analysis of Experimental Data, page 3-1, DOE-HDBK-3010-94, December 1994, http://www.orau.gov/ddsc/dose/doehandbook.pdf.

[145] Information provided by Patrick McClure, Los Alamos National Laboratory, January 23, 2014.

Specific Activity (SA): A measure of the radioactivity of a material, expressed in curies (a measure of the number of radioactive disintegrations per second) per gram of material. This table shows SA for Pu-239PE.

Dose Conversion Factor (DCF): Multiplying SA by this factor converts SA to dose.

Dose is expressed in rem, a measure of ionizing radiation absorbed by human tissue.

DOE sets radiation exposure guidelines for MOI and CW in accidents that release radioactive material. The guideline dose for CW, 100 rem, is higher than that for MOI, 5 to 25 rem. The reason is that, just as workers in any hazardous occupation, such as mining or window washing, assume greater risk than the general public, so do workers in close proximity to SNM. The higher guideline reflects that risk. As noted in "Key Regulatory Terms," one expert lists a dose of between 0 and 25 rem as having "no detectable clinical effects; small increase in risk of delayed cancer and genetic effects," a dose of 25 to 100 rem as "serious effects on average individual highly improbable," and for 100-200 rem "minimal symptoms; nausea and fatigue with possible vomiting." Thus the doses in **Table B-1** and **Table B-2** are very low and, as noted in "Airborne Release Fraction," above, could be much lower.

Table B-2. Dose from a Plutonium Spill and Fire in RLUOB

For Selected Quantities of Plutonium

Type and Quantity (grams) of Plutonium		**Dose (rem) to:**	
Plutonium-239 Equivalent	**Weapons-Grade Plutonium**	**MOI**	**CW**
38.6	26	0.01	0.27
750	505	0.25	5.20
1,500	1,010	0.49	10.41
2,610	1,760	0.86	18.11
DOE guideline		5-25	100

Source: Table by Los Alamos National Laboratory, notes by CRS.

Abbreviations: MOI, Maximally Exposed Offsite Individual; CW, Collocated Worker; DOE guideline, maximum dose (in rem) per DOE regulations.

Conversion of g Pu-239E to g WGPu: The fissile material in pits is Pu-239. However, the actual material in pits, WGPu, is not pure Pu-239. Instead, it is composed mainly of that isotope as well as small amounts of other plutonium isotopes, some of which are more radioactive than Pu-239. The ratio of Pu-239 to other plutonium isotopes varies slightly from one batch to another, and the ratio changes over time as plutonium undergoes radioactive decay, with each isotope having a different rate of decay. It is useful to convert all radioactive material in a building to a single unit, in this case g Pu-239E, to facilitate compliance with MAR limits. Given the isotopic variance inherent in WGPu, no single factor can precisely convert g WGPu to g Pu-239E for all batches of WGPu. For most purposes, and for purposes of this table, multiplying g Pu-239E by 0.67 yields g WGPu.

RLUOB, as a Radiological Facility, is only permitted to hold 38.6 g Pu-239E. In order for RLUOB to do the AC and some MC to support production in PF-4 of 80 pits per year, RLUOB would probably need to hold 1,000 g of weapons-grade plutonium, though a lesser amount, perhaps 500 g, might suffice. (As noted, it is not clear that RLUOB would have the floor space to do all the AC for that rate of production.) The table shows dose resulting from an accident that released those quantities of plutonium. The table includes 2,610 g Pu-239E (1,760 g WGPu) because that is the maximum amount of plutonium that a Hazard Category 3 building can hold.

The conclusion is that even in a worst-case accident, with RLUOB collapsed by an earthquake and all plutonium in the building spilled out, converted to plutonium oxide particles by a fire, and lofted into the air, the dose that an MOI or a CW would receive if RLUOB contained 1,010 g of WGPu would be at least an order of magnitude below DOE guidelines. That would still be the case even if RLUOB held 1,760 g of WGPu.

Appendix C. Security and Hazard Categories for Plutonium

Table C-1. Security and Hazard Categories for Plutonium

Security Category (SC)	SC for Plutonium Material Limits	Hazard Category (HC)	HC for Plutonium-239 Equivalent Material Limits
I	Assembled weapons/test devices; ≥2,000 g pure products;[a] ≥6,000 g high-grade materials[b]	(1)	N/A (Nuclear Reactor)
II	Less than SC I, but ≥400 g pure products; ≥2,000 g high-grade materials; ≥16,000 g low-grade materials[c]	2	>2,610 g Pu-239 Equivalent
III	Less than SC II, but ≥200 g pure products; ≥400 g high-grade materials; ≥3,000 g low-grade materials	3	Less than HC 2, but >38.6 g Pu-239 Equivalent
IV	Less than SC III	(Radiological)[d]	Less than HC 3

Source: Authority for Security Categories: DOE O[rder] 474.2 Chg 1, 8-3-11 (2011), Nuclear Material Control and Accountability, Attachment 2, page 2, http://www.fas.org/sgp/othergov/doe/o474-2.pdf

Authority for Hazard Categories: NA-1 SD G [Supplemental Guidance] 1027 (2011), Guidance on Using Release Fraction and Modern Dosimetric Information Consistently with DOE STD 1027-92, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23, Nuclear Safety Analysis Reports, Change Notice No. 1, approved 11-28-11, Attachment 2, Hazard Categorization Tables, Table 1, Revised Thresholds for Radionuclides, page 2-4, http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/NNSA_Supp_Guide_1027.pdf

a. Pure Products: pits, major components, button ingots, recastable metal, directly convertible materials.

b. High-Grade Materials: Carbides, oxides, solutions (>25g/L), nitrates, etc., fuel elements and assemblies, alloys and mixtures.

c. Low-Grade Materials: Solutions (1-25g/L), process residues requiring extensive reprocessing, Pu-238 (except waste)

d. A “Radiological” facility is actually not part of the Hazard Category system because it does not contain enough material.

Appendix D. Preliminary Outline of Potential Tasks Required for RLUOB to Exceed Hazard Category 3 Nuclear Facility Threshold Quantity

Los Alamos National Laboratory prepared the following document to indicate the types of tasks that would be necessary to enable RLUOB to contain more than 38.6 g Pu-239E under current statutes, regulations, DOE orders, DOE standards, administrative procedures, and other requirements. These tasks would convert RLUOB to an HC-3 facility. As will be seen, the list of tasks is extensive, and tasks derive from many sources. Note that while this is a list of tasks, many of these tasks would require extensive effort to complete, and some might lead to physical changes in RLUOB, such as seismic strengthening or added safety equipment.

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Approved for public release; distribution is unlimited.

Title: Preliminary Outline of Potential Tasks Required for RLUOB to Exceed Hazard Category-3 Nuclear Facility Threshold Quantity

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Intended for: Preliminary Planning and Discussions with NNSA and other Customers

September 2013

Preliminary Outline of Potential Tasks Required for RLUOB to Exceed Hazard Category-3 Nuclear Facility Threshold Quantity

I. Purpose

This document is to provide a high level outline of the activities required to upgrade Radiological Laboratory Utility/Office Building (RLUOB) to a hazard category-3 (HC-3) nuclear facility (>38.6 grams up to 2,600 grams of ^{239}Pu equivalent).

II. Scope

The outline of tasks listed below is drawn from Codes of Federal Regulations (CFR), Department of Energy (DOE) Orders (DOE O), Standards (DOE STD) and Guides (DOE G), and Los Alamos National Laboratory (LANL) internal procedures. It is aligned to functional organizations to facilitate review by line organizations and eventual scheduling.

III. Potential Tasks

Hazards Analysis

- Define source term in sufficient detail to support the hazards analysis.
- Perform hazard categorization per DOE-STD-1027, *Hazard Categorization and Accident Analysis*, and LANL safety basis procedure (SBP) 114-2, *Hazard Evaluation and Accident Analysis*.
    - Perform initial hazards screening
    - Develop hazards analysis to finalize the hazard categorization.

External Stakeholders

- National Nuclear Security Administration (NNSA) and Department of Defense (DoD)– program customers
- NNSA/Los Alamos Field Office (LAFO)
- NNSA/Chief of Defense Nuclear Safety (CDNS)
- Defense Nuclear Facilities Safety Board (DNFSB)
- Interested Parties (public)

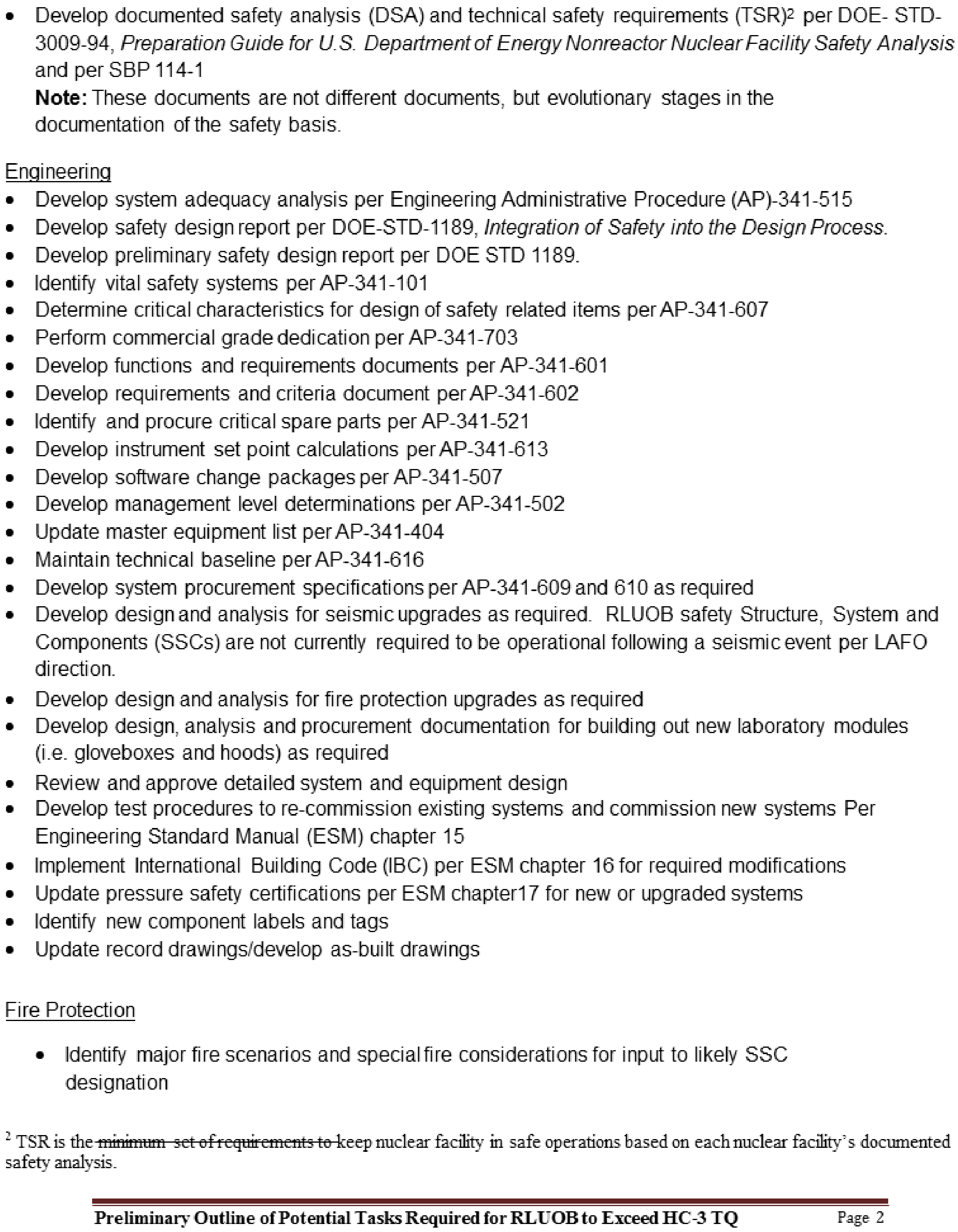
National Environment Policy Act (NEPA)

- Develop an environmental assessment per 40CFR1508.9, *Environmental assessment*.
- Develop an environmental impact statement if required by 40CFR1501.4 (*Whether to prepare an environmental impact statement*) in accordance with 40CFR1502 (*Environmental Impact Statement*) and DOE O 450 (*Environmental Protection Program*) and O 451.1B (*National Environmental Policy Act Compliance Program*)
- Review and update the Air Emission and Rad-NESHAP [1] Permit

Safety Analysis

- Develop safety design strategy per SBP 114-1, *Safety Basis Development for Projects*
- Develop conceptual safety design report per SBP 114-1
- Develop preliminary safety design report per SBP 114-1

[1] EPA National Emission Standards for Hazardous Air Pollutants for Radionuclides (Rad-NESHAP)



- Develop documented safety analysis (DSA) and technical safety requirements (TSR)[2] per DOE- STD-3009-94, *Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Safety Analysis* and per SBP 114-1

  Note: These documents are not different documents, but evolutionary stages in the documentation of the safety basis.

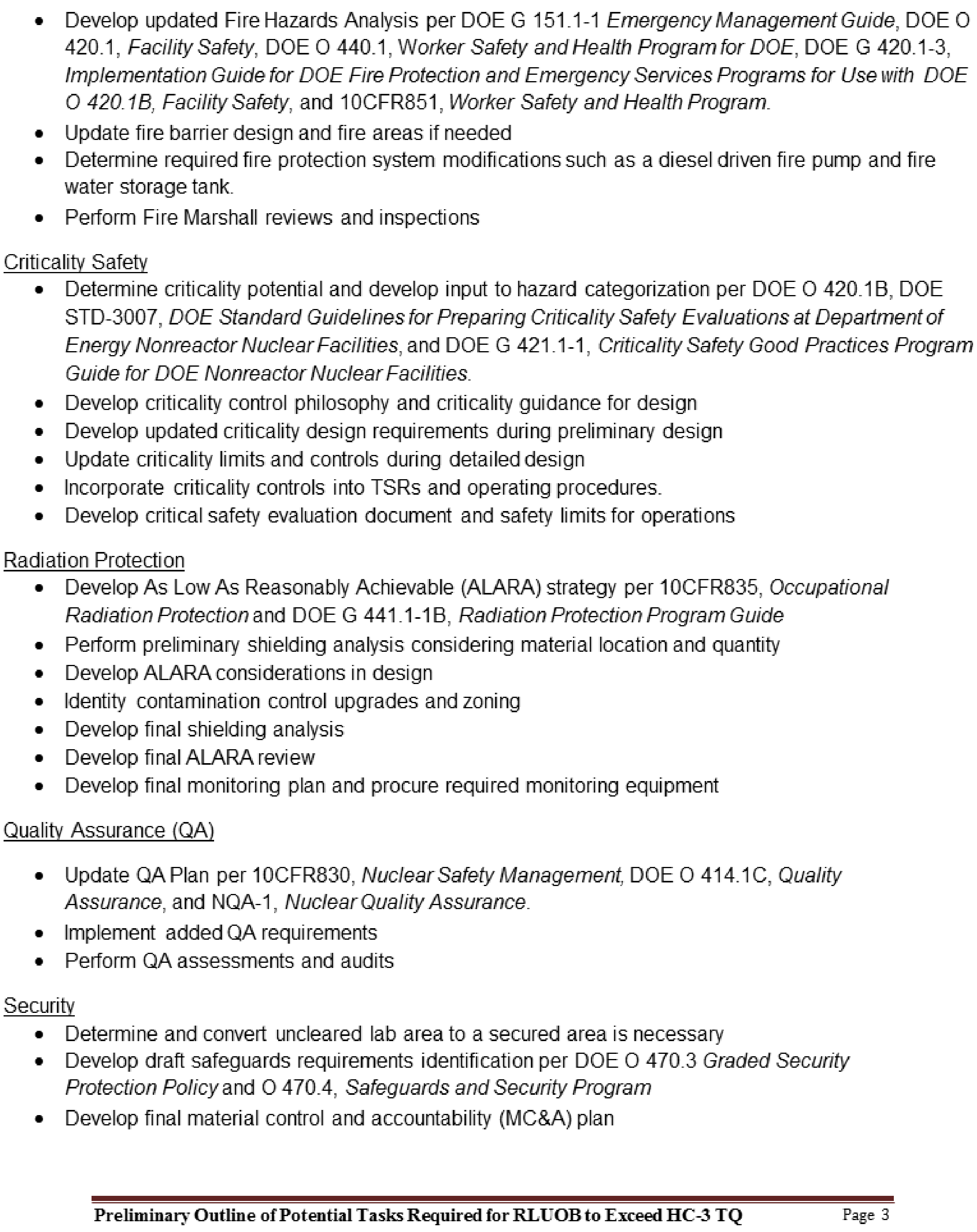
Engineering

- Develop system adequacy analysis per Engineering Administrative Procedure (AP)-341-515
- Develop safety design report per DOE-STD-1189, *Integration of Safety into the Design Process*.
- Develop preliminary safety design report per DOE STD 1189.
- Identify vital safety systems per AP-341-101
- Determine critical characteristics for design of safety related items per AP-341-607
- Perform commercial grade dedication per AP-341-703
- Develop functions and requirements documents per AP-341-601
- Develop requirements and criteria document per AP-341-602
- Identify and procure critical spare parts per AP-341-521
- Develop instrument set point calculations per AP-341-613
- Develop software change packages per AP-341-507
- Develop management level determinations per AP-341-502
- Update master equipment list per AP-341-404
- Maintain technical baseline per AP-341-616
- Develop system procurement specifications per AP-341-609 and 610 as required
- Develop design and analysis for seismic upgrades as required. RLUOB safety Structure, System and Components (SSCs) are not currently required to be operational following a seismic event per LAFO direction.
- Develop design and analysis for fire protection upgrades as required
- Develop design, analysis and procurement documentation for building out new laboratory modules (i.e. gloveboxes and hoods) as required
- Review and approve detailed system and equipment design
- Develop test procedures to re-commission existing systems and commission new systems Per Engineering Standard Manual (ESM) chapter 15
- Implement International Building Code (IBC) per ESM chapter 16 for required modifications
- Update pressure safety certifications per ESM chapter17 for new or upgraded systems
- Identify new component labels and tags
- Update record drawings/develop as-built drawings

Fire Protection

- Identify major fire scenarios and special fire considerations for input to likely SSC designation

[2] TSR is the ~~minimum set of requirements to~~ keep nuclear facility in safe operations based on each nuclear facility's documented safety analysis.



- Develop updated Fire Hazards Analysis per DOE G 151.1-1 *Emergency Management Guide*, DOE O 420.1, *Facility Safety*, DOE O 440.1, *Worker Safety and Health Program for DOE*, DOE G 420.1-3, *Implementation Guide for DOE Fire Protection and Emergency Services Programs for Use with DOE O 420.1B, Facility Safety*, and 10CFR851, *Worker Safety and Health Program*.
- Update fire barrier design and fire areas if needed
- Determine required fire protection system modifications such as a diesel driven fire pump and fire water storage tank.
- Perform Fire Marshall reviews and inspections

Criticality Safety

- Determine criticality potential and develop input to hazard categorization per DOE O 420.1B, DOE STD-3007, *DOE Standard Guidelines for Preparing Criticality Safety Evaluations at Department of Energy Nonreactor Nuclear Facilities*, and DOE G 421.1-1, *Criticality Safety Good Practices Program Guide for DOE Nonreactor Nuclear Facilities*.
- Develop criticality control philosophy and criticality guidance for design
- Develop updated criticality design requirements during preliminary design
- Update criticality limits and controls during detailed design
- Incorporate criticality controls into TSRs and operating procedures.
- Develop critical safety evaluation document and safety limits for operations

Radiation Protection

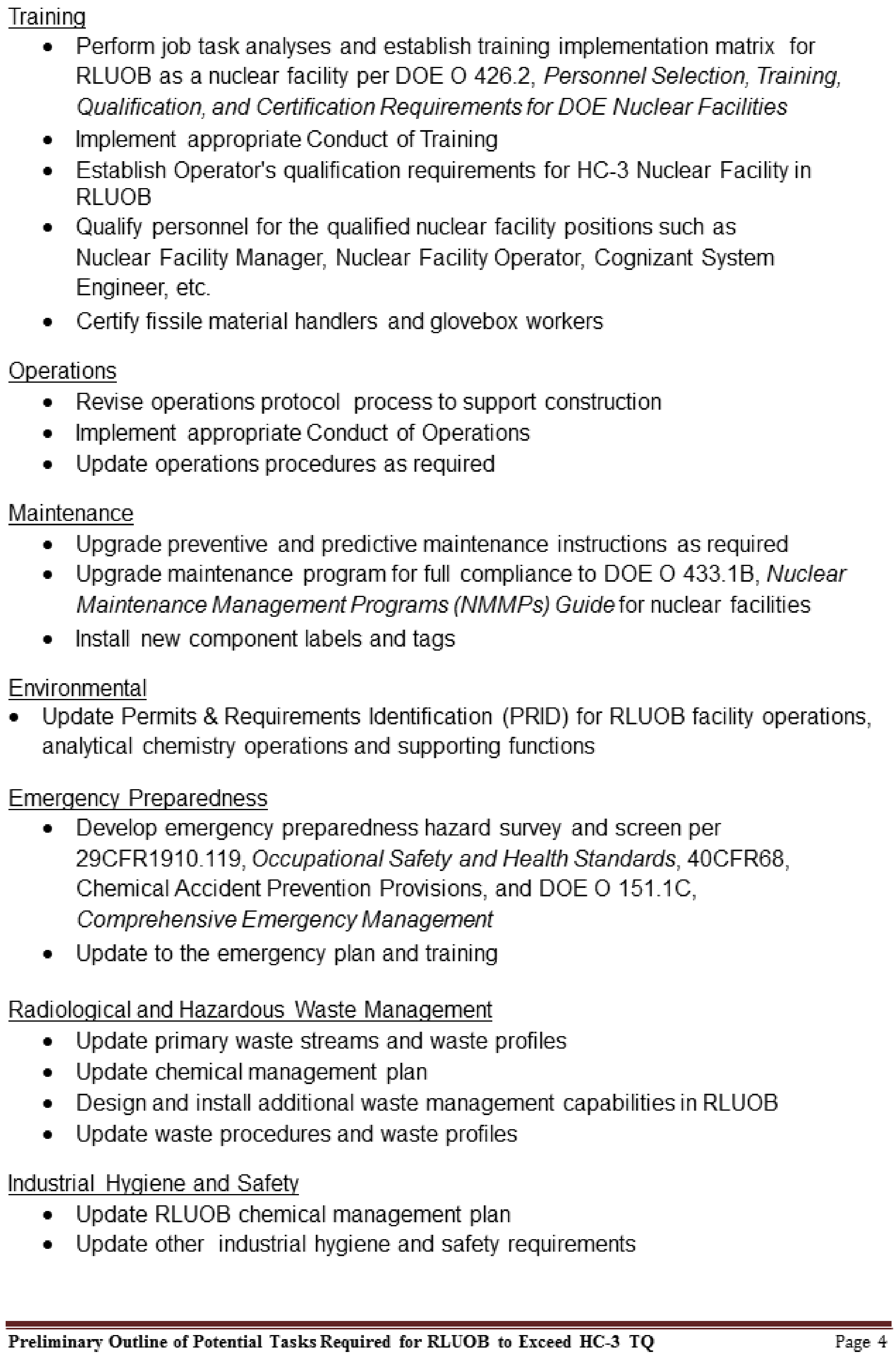
- Develop As Low As Reasonably Achievable (ALARA) strategy per 10CFR835, *Occupational Radiation Protection* and DOE G 441.1-1B, *Radiation Protection Program Guide*
- Perform preliminary shielding analysis considering material location and quantity
- Develop ALARA considerations in design
- Identity contamination control upgrades and zoning
- Develop final shielding analysis
- Develop final ALARA review
- Develop final monitoring plan and procure required monitoring equipment

Quality Assurance (QA)

- Update QA Plan per 10CFR830, *Nuclear Safety Management,* DOE O 414.1C, *Quality Assurance*, and NQA-1, *Nuclear Quality Assurance*.
- Implement added QA requirements
- Perform QA assessments and audits

Security

- Determine and convert uncleared lab area to a secured area is necessary
- Develop draft safeguards requirements identification per DOE O 470.3 *Graded Security Protection Policy* and O 470.4, *Safeguards and Security Program*
- Develop final material control and accountability (MC&A) plan



Training

- Perform job task analyses and establish training implementation matrix for RLUOB as a nuclear facility per DOE O 426.2, *Personnel Selection, Training, Qualification, and Certification Requirements for DOE Nuclear Facilities*
- Implement appropriate Conduct of Training
- Establish Operator's qualification requirements for HC-3 Nuclear Facility in RLUOB
- Qualify personnel for the qualified nuclear facility positions such as Nuclear Facility Manager, Nuclear Facility Operator, Cognizant System Engineer, etc.
- Certify fissile material handlers and glovebox workers

Operations

- Revise operations protocol process to support construction
- Implement appropriate Conduct of Operations
- Update operations procedures as required

Maintenance

- Upgrade preventive and predictive maintenance instructions as required
- Upgrade maintenance program for full compliance to DOE O 433.1B, *Nuclear Maintenance Management Programs (NMMPs) Guide* for nuclear facilities
- Install new component labels and tags

Environmental

- Update Permits & Requirements Identification (PRID) for RLUOB facility operations, analytical chemistry operations and supporting functions

Emergency Preparedness

- Develop emergency preparedness hazard survey and screen per 29CFR1910.119, *Occupational Safety and Health Standards*, 40CFR68, Chemical Accident Prevention Provisions, and DOE O 151.1C, *Comprehensive Emergency Management*
- Update to the emergency plan and training

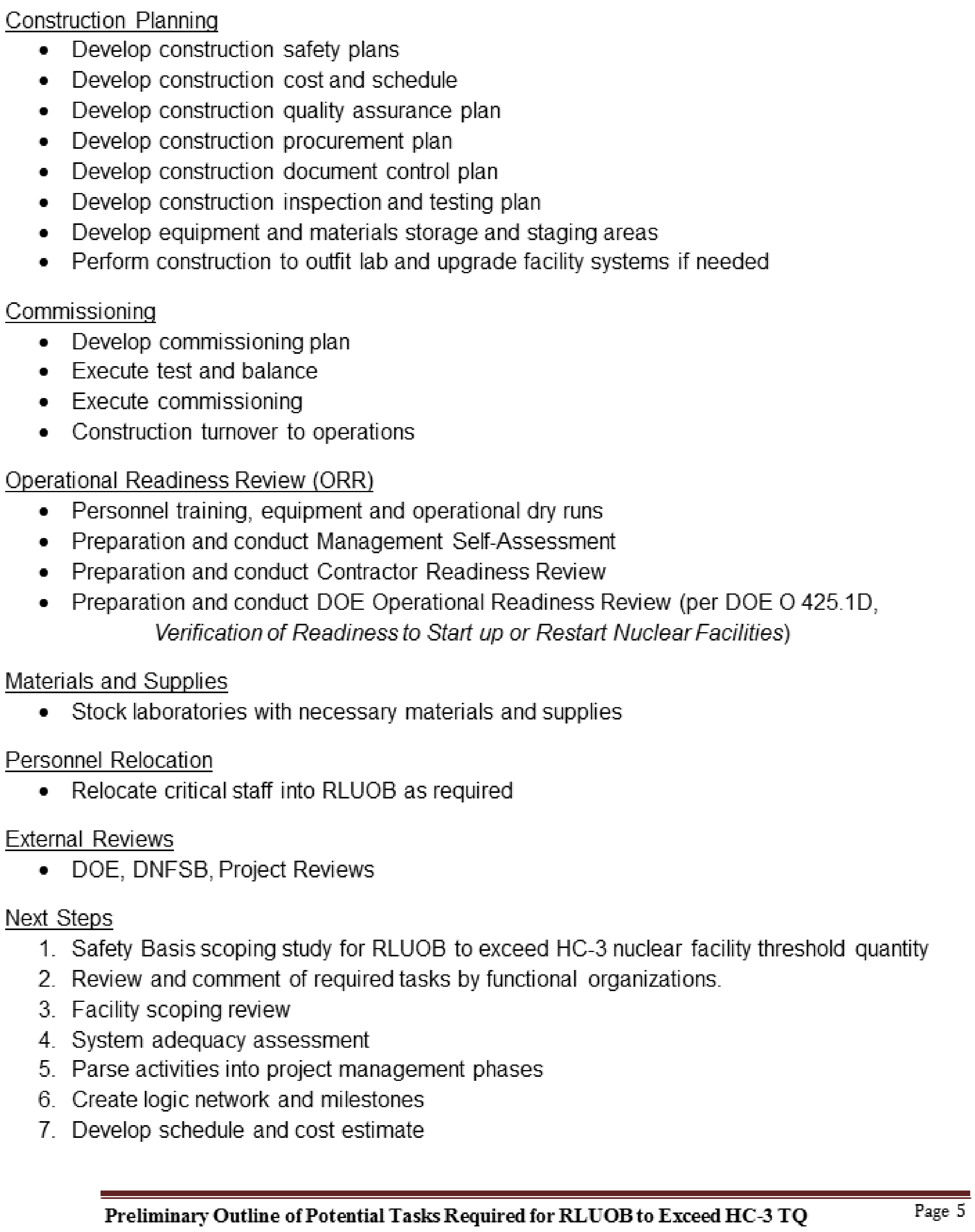
Radiological and Hazardous Waste Management

- Update primary waste streams and waste profiles
- Update chemical management plan
- Design and install additional waste management capabilities in RLUOB
- Update waste procedures and waste profiles

Industrial Hygiene and Safety

- Update RLUOB chemical management plan
- Update other industrial hygiene and safety requirements

Preliminary Outline of Potential Tasks Required for RLUOB to Exceed HC-3 TQ Page 4



Construction Planning

- Develop construction safety plans
- Develop construction cost and schedule
- Develop construction quality assurance plan
- Develop construction procurement plan
- Develop construction document control plan
- Develop construction inspection and testing plan
- Develop equipment and materials storage and staging areas
- Perform construction to outfit lab and upgrade facility systems if needed

Commissioning

- Develop commissioning plan
- Execute test and balance
- Execute commissioning
- Construction turnover to operations

Operational Readiness Review (ORR)

- Personnel training, equipment and operational dry runs
- Preparation and conduct Management Self-Assessment
- Preparation and conduct Contractor Readiness Review
- Preparation and conduct DOE Operational Readiness Review (per DOE O 425.1D, *Verification of Readiness to Start up or Restart Nuclear Facilities*)

Materials and Supplies

- Stock laboratories with necessary materials and supplies

Personnel Relocation

- Relocate critical staff into RLUOB as required

External Reviews

- DOE, DNFSB, Project Reviews

Next Steps

1. Safety Basis scoping study for RLUOB to exceed HC-3 nuclear facility threshold quantity
2. Review and comment of required tasks by functional organizations.
3. Facility scoping review
4. System adequacy assessment
5. Parse activities into project management phases
6. Create logic network and milestones
7. Develop schedule and cost estimate

Appendix E. Comparison of Seismic Resiliency of CMR and RLUOB[146]

Structural engineers strive to make buildings safe against possible earthquake ground motion. The model building codes are constantly evolving and incorporate lessons learned from the response of buildings in real earthquakes. Prior to the 1933 Long Beach earthquake, the model building codes had very few seismic requirements. This earthquake led to new requirements being added to codes. Another big change in design codes came after the 1971 San Fernando earthquake, which showed that reinforced concrete buildings with certain characteristics were prone to collapse in large earthquakes. Since that time, the codes have implemented much stricter rules for the design of both steel and reinforced-concrete buildings.

RLUOB was designed and constructed to withstand earthquake motion much better than CMR. CMR was constructed in the late 1940s and is not very seismically robust. In fact, it is a "non-ductile reinforced concrete moment frame" – the very type of structure that the 1971 San Fernando earthquake proved to be vulnerable to collapse in earthquakes. LANL estimates that it is vulnerable to collapse in an earthquake expected to strike with a frequency of once in 167 years to once in 500 years.

While RLUOB, as a Radiological Facility, could have been built of light-duty design and materials because it was to have only about 6 grams of WGPu, NNSA decided to build it to a much higher standard in order to understand issues that could be encountered in building CMRR-NF. Specifically, RLUOB was designed and built to the 2003 Edition of the International Building Code supplemented to meet the requirements for seismic Performance Category 2 as provided in DOE Standard 1020-2002,[147] i.e., able to withstand ground motions associated with an earthquake expected to strike with a frequency of once in 2,500 years. It has a special reinforced concrete structure for the basement, first (laboratory), and second (office) floors. The third and fourth floors, which are also for offices, are constructed of steel framing designed to the standards of an emergency response building (e.g., a hospital or fire station), so they are more seismically robust than a typical office building. As a result, RLUOB is much sturdier than it needed to be.

Based on LANL's models of seismic performance, collapsing RLUOB would take an earthquake with 4 to 12 times more force than an earthquake that would collapse CMR. Its better performance is largely the result of being able to dissipate energy through bending deformations in its steel frame. This energy absorption is key in seismic design. Brittle structures, such as CMR, cannot dissipate energy and are hence more susceptible to collapse when the ground motions exceed the building's design basis. In addition, the earthquake risk in the Los Alamos area is much better known today than it was when CMR was constructed. For example, it is now known that there is a seismic fault directly under CMR but not under RLUOB. Designing RLUOB with a more accurate understanding of the seismic characteristics of the underlying geology increases the ability of that building to withstand potential ground motion.

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[146] Prepared by Michael Salmon, structural engineer and seismic analyst, Los Alamos National Laboratory, December 2013.

[147] DOE updated this Standard in December 2012: http://energy.gov/sites/prod/files/2013/06/f1/DOE-STD-1020-2012.pdf.

Appendix F. Space Requirements for Analytical Chemistry to Support Production of 80 Pits Per Year[148]

LANL has never analyzed the space requirements for AC to support 80 ppy. However, in 2007 it analyzed the AC capacity of CMRR-NF plus RLUOB, and found that they could, together, support AC for 40-50 ppy. In the original plan for building both RLUOB and CMRR NF, there was to be a total of 16,500 square feet (sf) of laboratory space devoted to AC (see table below). If RLUOB were allowed to hold 1,000 g WGPu and CMRR-NF were to remain deferred, the amount of space for AC in RLUOB would exceed that value without incurring the operational penalty of having to use gloveboxes in PF-4 to the extent that would otherwise be required.

Regarding the latter point, a few types of AC can be done in gloveboxes. For example, sample management, which involves cutting pieces of plutonium from a larger sample, and analysis that uses solid samples on the order of 1 to 5 g of plutonium, can be done in gloveboxes because they do not require fine manipulation. In contrast, most AC uses samples of a few drops of liquid with milligram (or smaller) quantities of plutonium; such samples require fine manipulation, which is much easier to do in hoods. Performing AC tasks of the latter type in gloveboxes exacts a penalty in the time required to do the analysis, which slows throughput and thereby reduces capacity.

By performing AC tasks best suited for hoods in RLUOB and AC tasks that can be performed in gloveboxes in PF-4, by studying how to maximize efficient use of space for AC, and perhaps by using two shifts per day instead of one, it seems likely that a configuration of PF-4 plus RLUOB with 1,000 g WGPu would have the space both to fabricate 80 ppy and to provide the AC necessary to support that level of production. A detailed analysis would be needed to reach this conclusion with confidence.

Table F-1. Space for Plutonium Analytical Chemistry in Three Scenarios

Scenario		Analytical Chemistry Space (square feet)[a]			
Buildings	RLUOB MAR (g WGPu)	PF-4	RLUOB	CMRR- NF	Total
RLUOB + CMRR-NF	6		6,750	9,750	16,500
Post-NF Deferral Plan	26	5,600	10,500		16,100
Expanded RLUOB MAR[b]	~1,000	2,400	15,000		17,400

a. Space excludes AC for Pu-238, which has been integrated into the Pu-238 operational space in PF-4. This table excludes space for MC because MC is relatively insensitive to production rate, so increasing that rate to 80 ppy might result in only a slight increase, if any, in MC space needed.

b. While RLUOB has 19,500 sf of lab space, about 4,500 sf would be used for purposes other than AC, such as MC and preparation of chemicals needed in AC. Space listed here would be used for AC for all plutonium programs in PF-4 except Pu-238. However, pits account for a large fraction of the total AC.

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[148] Text and table prepared by Brett Kniss, Program Director, Plutonium Strategy Implementation, Los Alamos National Laboratory, December 18, 2013.

Appendix G. Abbreviations

AC	Analytical chemistry
ARF	Airborne Release Fraction
ARIES	Advanced Recovery and Integrated Extraction System
CD	Critical Decision
CEQ	Council on Environmental Quality
CMR	Chemistry and Metallurgy Research Building
CMRR	Chemistry and Metallurgy Research Replacement Project
CMRR-NF	Chemistry and Metallurgy Research Replacement Nuclear Facility
CNPC	Consolidated Nuclear Production Center
CW	Collocated Worker
DBA	Design Basis Accident
DBE	Design Basis Earthquake
DNFSB	Defense Nuclear Facilities Safety Board
DOD	Department of Defense
DOE	Department of Energy
g	gram(s)
HC	Hazard Category
HEPA	High-efficiency particulate air (type of filter)
INL	Idaho National Laboratory
kg	kilogram(s)
LANL	Los Alamos National Laboratory
LEP	Life Extension Program
LLNL	Lawrence Livermore National Laboratory
LPF	Leak Path Factor
MAR	Material At Risk
MC	Materials Characterization
MOI	Maximally-exposed Offsite Individual
MOX	Mixed oxide
MPF	Modern Pit Facility
PF-4	Plutonium Facility 4 (main plutonium building at Los Alamos National Laboratory)
ppy	pits per year
Pu	Plutonium
Pu-239E	Plutonium-239 equivalent
R&D	research and development
RF	Respirable Fraction
RLB	(hypothetical) Radiological Laboratory Building
RLUOB	Radiological Laboratory/Utility/Office Building

ROD	Record of Decision
SEAB	Secretary of Energy Advisory Board
sf	square foot or square feet
SNM	Special Nuclear Material
SRS	Savannah River Site
TA-55	Technical Area 55 (area that includes PF-4)
TRP	TA-55 Reinvestment Project
UPF	Uranium Processing Facility
WGPu	Weapons-grade plutonium
WIPP	Waste Isolation Pilot Plant

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The Defense Nuclear Facilities Safety Board declined to comment on drafts of this report.

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In Brief: U.S. Nuclear Weapon "Pit" Production: Background and Options

Jonathan E. Medalia
Specialist in Nuclear Weapons Policy

March 20, 2014

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Summary

Congress is involved in the long-running and costly decision regarding the future production of “pits”; a pit is a nuclear weapon’s plutonium core. Rocky Flats Plant (CO) mass-produced pits during the Cold War; production ceased in 1989. The Department of Energy (DOE), which maintains U.S. nuclear weapons, then established a small pit manufacturing capability at PF-4, a building at Los Alamos National Laboratory (LANL) (NM). PF-4 has made at most 11 pits per year (ppy). DOE also proposed higher-capacity facilities; none came to fruition.

U.S. policy is to maintain existing nuclear weapons. To do this, the Department of Defense has stated that it needs DOE to have the capacity to produce 50-80 ppy by 2030. This report focuses on options to reach 80 ppy. A separate debate, not discussed here, is the validity of the requirement; a lower capacity would be simpler and less costly to attain.

Pit production requires many tasks, but this report focuses on two: pit fabrication, which forms plutonium into precise shapes, and analytical chemistry (AC), which monitors the composition of each pit. Any feasible option requires sufficient “space” (laboratory floor space) and “Material At Risk” (MAR) allowance. Each building for plutonium work is permitted a specified amount of MAR, i.e., radioactive material (adjusted for radioactivity) that could be released by an event like an earthquake.

Pits can only be fabricated in PF-4. Increasing its capacity to 80 ppy would require making more MAR and more space available in that building, which in turn would require moving out radioactive material and freeing up space. Both could be done, for example, by moving pit casting or work on plutonium-238 (Pu-238), which is much more radioactive than the plutonium used in weapons, out of PF-4.

One pit fabrication option is to build one or more “modules” to move high-MAR work from PF-4. Modules would be reinforced-concrete structures buried near PF-4. Another option is to use buildings at Idaho National Laboratory or Savannah River Site (SRS) (SC); both sites have done work with Pu-238.

Higher capacity also requires more AC, which increases in tandem with capacity. Most AC is not time-sensitive, so some of it could be done at sites other than LANL. PF-4 is not suitable for most AC work. Thus increasing pit production would also require finding one or more sites for AC. AC requires much less MAR and much more space than pit fabrication, so AC options differ from pit fabrication options. Buildings at Lawrence Livermore National Laboratory (CA) and SRS have ample space suitable for AC. LANL would also need a significant AC capacity to support pit production and other work. An option would be to modify the new Radiological Laboratory-Utility-Office Building (RLUOB) so it could handle more plutonium, permitting it to do more AC.

This report shows that many options are available for making 80 ppy, but it cannot determine which, if any, could support that capacity because data do not exist on how much MAR and space are needed for AC and pit fabrication for 80 ppy. Likewise, there are little to no data on cost. However, the report raises questions that Congress may wish to have answered in order to decide how to proceed:

- Is an 80-ppy capacity needed?
- If so, how much space and MAR in PF-4 would fabrication of 80 ppy require?
- Could sufficient space be made available by repurposing PF-4 space? How might enough MAR allowance be made available?
- What are the pros, cons, and costs of Pu-238 options?
- If modules are built, how many would be needed and what would they cost?
- How much space and MAR would AC for 80 ppy require?
- What are the pros, cons, and costs of having SRS or LLNL perform some AC?
- What would it cost to modify RLUOB?

This report summarizes a more detailed report, CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*, by Jonathan E. Medalia.

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Background

Congress is involved in the long-running and costly decision regarding the future production of "pits"; a pit is the plutonium core of the primary stage of a nuclear weapon. When imploded by high explosives, a pit becomes so compressed that it results in a nuclear explosion that provides the energy to detonate the weapon's main (secondary) stage. During the Cold War, the Rocky Flats Plant (CO) made pits on an industrial scale, sometimes over 1,000 pits per year (ppy). Rocky Flats ceased pit production in 1989. Since then, the United States has made at most 11 ppy despite several failed attempts to build a facility able to produce pits at a higher rate. Yet the Department of Defense (DOD) requires the National Nuclear Security Administration (NNSA), the separately-organized component of the Department of Energy (DOE) in charge of the U.S. nuclear weapons program, to have the capacity to make 50-80 ppy by 2030.[1]

U.S. policy is to "not develop new nuclear warheads … or provide for new military capabilities."[2] However, weapon components age, so life extension programs (LEPs) are underway or planned for each existing weapon type in sequence. Some LEPs will use a weapon's original pit, and other LEPs may use retired pits from other weapon types. Still other LEPs may use newly-manufactured pits, such as to replace original pits that have deteriorated or to incorporate new safety and security features. Some experts argue that additional pit manufacturing capacity is needed to replace pits that encounter problems out of sequence or to hedge against unanticipated geopolitical developments. Others reply that a capacity much less than 80 ppy would suffice. While there is debate over what capacity is needed, this report has a different focus: how to achieve a capacity of 80 ppy. This report summarizes the much more detailed CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*, by Jonathan E. Medalia.

Pit production involves precisely shaping plutonium, a hazardous, radioactive, physically quirky metal. Production also requires supporting tasks, notably analytical chemistry (AC, defined below). Currently, Los Alamos National Laboratory (LANL) (NM) produces pits at its PF-4 building, and conducts AC and other supporting tasks at its Chemistry and Metallurgy Research (CMR) building.

Several terms are essential for understanding pit production options:

- **Material At Risk (MAR):** DOE defines this term as "the amount of radioactive materials … available to be acted on by a given physical stress."[3] For LANL, earthquakes pose the most severe anticipated physical stress. Each building using radioactive material has a MAR allowance specific to that building.
- **Hazard Category (HC):** A categorization of buildings based on the amount of radioactive material a building is designed to hold. The HC system defines the

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[1] Testimony of Andrew Weber, Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, in U.S. Congress. Senate. Committee on Armed Services. Subcommittee on Strategic Forces. *Hearing to Receive Testimony on Nuclear Forces and Policies in Review of the Defense Authorization Request for Fiscal Year 2014 and the Future Years Defense Program*, April 17, 2013, p. 15.

[2] U.S. Department of Defense. *Nuclear Posture Review Report,* April 2010, p. 39.

[3] U.S. Department of Energy. DOE Handbook: *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities,* Vol. I, Analysis of Experimental Data, DOE-HDBK-3010-94, December 1994, p. xix.

construction type and safety systems needed to keep radiation dose to persons within limits defined by DOE in the event of an accident or building collapse.

- **Radiological Facility:** The lower limit for radioactive material in a building in the HC system is about 26 grams of weapons-grade plutonium (WGPu), which contains mostly plutonium-239 but also other isotopes of plutonium. Buildings with less than this quantity are "Radiological Facilities." They require no special security measures because they have so little material.
- **Security Category (SC):** A categorization of buildings based on the amount and form of radioactive material in a building. The intent of the SC system is to determine what level of security a building needs based on the "attractiveness" of its materials, especially to terrorists. For example, WGPu in metallic form, in quantities sufficient to make a bomb, would be highly attractive, and a building containing large quantities of it requires armed guards, intrusion detection systems, special fencing, and the like. In contrast, WGPu dissolved in a large quantity of acid is much less attractive, so requires much less security.
- **Analytical Chemistry (AC):** AC analyzes many plutonium samples taken from each pit at various stages in its manufacture. AC determines the isotopic composition of WGPu, the amount of other materials added to WGPu, and the amount of impurities. Most AC uses tiny samples, such as a few milligrams of plutonium dissolved in a small amount of acid, so it is low-MAR and low-SC. On the other hand, AC requires a substantial amount of laboratory floor space.
- **Plutonium-238 (Pu-238):** Pu-238 is highly radioactive. Is main use is to power space probes. It bears on pit production options because it occupies 9,600 sf in PF-4 out of 60,000 sf, and accounts for 40 percent of PF-4's MAR allowance.

Pit Fabrication Options

The basis for the following options is that PF-4 is the only U.S. building able to produce pits, as it has high security, a high MAR allowance, and pit production equipment. Increasing its capacity to 80 ppy would entail more production equipment and more MAR. Thus higher capacity requires making MAR and space available. Some space is currently available; more might be as well. Three main tasks contribute to MAR in PF-4: Pu-238 work, pit fabrication, and recovery of plutonium from acid solution. Of these, only Pu-238 may plausibly be moved to another site.

Options Using Modules

One option is to build "modules" at LANL so high-MAR work like processing Pu-238 or casting pits could be moved from PF-4. Preliminary plans envision modules as buried reinforced-concrete structures with 3,000 to 5,000 sf of lab space. Each would be built for a specific task. They would be a few hundred yards from PF-4, and connected to it by a tunnel.

Arguments for modules follow: Since each module would be built for a specific task, each would meet regulatory requirements that apply only to it, rather than having to meet the most stringent regulatory requirements that apply to any work in an entire large building. Modules would draw on many support features offered by that building, such as shipping and receiving, security, temporary waste storage, and a storage vault for nuclear materials. Modules would arguably be faster and less costly to build than the large facilities proposed in the past that were canceled or deferred due to cost growth and schedule slippage. Reducing MAR in PF-4 would extend the life of that building if its MAR allowance were reduced over time as a result of more stringent regulations, problems that emerge in the building, increased calculation of seismic threat, etc.

Arguments against modules follow: Modules would not be needed if high-MAR work could be done in existing buildings, as described below. Even if modules are needed, they are arguably not needed now, as PF-4's service life could be extended. While they could use some of PF-4's infrastructure, they would need much infrastructure of their own, such as for ventilation and fire suppression, as well as special filters to prevent plutonium from escaping into the air in the event of an accident. Modules might cost billions of dollars because they would be high-HC and, for pit casting, high-SC as well. NNSA's cost estimation for major weapons and facilities projects has fallen short in the past; could Congress have confidence in cost estimates for modules?

Options Using Existing Buildings

Another approach is to use existing buildings. Most of the nuclear weapons complex was built during the Cold War and was sized to produce, at times, over 1,000 weapons per year. Thus existing buildings in the complex have much unused space, some of which is suitable for high-MAR work. These buildings might require modifications.

At least two sites could house the Pu-238 mission. Idaho National Laboratory (INL) and Savannah River Site (SRS) (SC) have both done work with Pu-238. Both have buildings that could be used for this purpose, Building CPP-1634 at INL and H Canyon and HB-Line at SRS. DOE prepared a study in 2013 on these options and found that both sites could be used for this purpose, at a cost between $122 million and $272 million.[4] This cost estimate is preliminary.

Analytical Chemistry Options

There are two sources of demand for AC capacity. CMR, most of which was built in 1952, does most AC for pit production, but is scheduled to halt operations around 2019; its work would have to be moved elsewhere. Higher capacity also requires more AC, as the two increase in tandem. PF-4 is not suitable for most AC work. Thus increased pit production would also require finding one or more sites for AC.

Options at Sites Other Than Los Alamos

Several approaches could provide AC space. Some AC could be done at a site other than LANL, as most AC is confirmatory rather than time-urgent, allowing some leeway in when samples are analyzed. During the Cold War, SRS produced WGPu for as much as several hundred ppy. All this plutonium required AC, and SRS has two facilities, F/H Laboratory and Building 773-A, that conducted AC and remain suitable for AC. Each has enough space for AC for 80 ppy.

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[4] U.S. Department of Energy. Space and Defense Power Systems. Radioisotope Heat Source Infrastructure Review Team. "Evaluation of Radioisotope Fuel Processing and Heat Source Fabrication Infrastructure Capabilities, Final Report," May 2013, p. 4-4.

Building 332 at Lawrence Livermore National Laboratory (LLNL) used to have the same HC and SC as PF-4, and formerly handled large quantities of WGPu, such as to build nuclear explosive devices for testing. However, NNSA directed LLNL to remove almost all the plutonium from this building to lower its Security Category. This work was completed in 2012. This action greatly reduced the security cost and the amount of weapons-usable material potentially vulnerable to theft. However, the building has ample space and other attributes suitable for AC work, and could handle AC for 80 ppy. Both SRS and LLNL could handle the MAR associated with AC in support of producing 80 ppy, though shipment of samples to LLNL would have to be staggered to avoid breaching its MAR limit.

Options at Los Alamos

Analysts have argued that it would not be desirable to perform all AC at a site other than LANL. All plutonium work requires AC. LANL, as the "center of excellence" for plutonium, requires AC, and would need a significant AC capacity for pit production, such as for quick-turnaround analyses, for solving problems, for maintaining expertise and equipment, and for training. On the other hand, it may be desirable to have one or perhaps two other sites perform AC to support pit production to distribute expertise, to cross-check AC at LANL, to accommodate a surge in demand, and to have a backup in case of problems with AC facilities at LANL.

PF-4 performs some AC, and could perform somewhat more. However, it is unsuitable for large-scale AC because most AC is best done in open-front hoods, which require a massive ventilation capacity to draw air into the hoods in order to keep acid and plutonium from contaminating lab rooms. It would be very costly, if not impossible, to retrofit that capacity into PF-4. Besides, low-MAR activities like AC are an inefficient use of the valuable high-MAR space at PF-4. Another possibility is to use an existing building at LANL, the Radiological Laboratory-Utility-Office Building (RLUOB, pronounced rulob). RLUOB was completed in FY2010 has 19,500 sf of laboratory space, and has a massive ventilation system. There are three possibilities.

- Use RLUOB for AC with 26 grams of WGPu. Since it is a Radiological Facility, that is the most it can hold under existing regulations. Twenty-six grams is enough to perform a substantial amount of AC because many AC samples are a few milligrams of plutonium dissolved in a small amount of acid. However, 26 grams of plutonium—the volume of two nickels—is nowhere near enough for large-scale AC. LANL has not studied how much plutonium the AC for 80 ppy would require, but it estimates the figure is on the order of 500 to 1,000 grams. Similarly, LANL has not studied in detail how much floor space the AC for 80 ppy would require, but estimates that if all laboratory space in RLUOB could be used with 500-1,000 grams of plutonium and if some additional space could be made available for AC in PF-4, that might suffice.
- Convert RLUOB from a Radiological Facility to an HC-3 building, which would permit it to hold 1,750 grams of WGPu. LANL estimated that this conversion would cost between $15 million and $50 million.[5] This cost estimate is preliminary and would require further study and validation.

---

[5] Leasure, C. L., M. M. Nuckols, et al., "Los Alamos Initial Response for Maintaining Capabilities with Deferral of the CMRR Nuclear Facility Project," Los Alamos National Laboratory, LA-CP-12-00470 (UCNI), April 16, 2012. The study is categorized as unclassified controlled nuclear information, so is not available for use in this report.

- Create an exemption for RLUOB to hold HC-3 quantities of plutonium without being converted to HC-3. This approach would probably permit NNSA to halt work in CMR by 2019, removing workers and plutonium from a building that is much more at risk of collapse from an earthquake than is RLUOB. While RLUOB is not HC-3, LANL calculated that the radiation dose resulting if RLUOB, with 1,000 grams of WGPu, collapsed in an earthquake would be far below the standard set by DOE. On the other hand, some would object to modifying regulations, especially for buildings housing radioactive material.

Questions for Congress

This report shows that many options could address DOD's requirement for 80 ppy, but it cannot determine which, if any, could meet this requirement because data do not exist on how much MAR and space are needed for AC and pit fabrication for 80 ppy. Likewise, there are little to no data on cost. However, this report raises questions that Congress may wish to have answered in order to decide how to proceed. Questions include:

- Is an 80-ppy capacity needed?
- If so, how much space and MAR in PF-4 would fabrication of 80 ppy require?
- Could that amount of space be made available by repurposing PF-4 space? If not, what changes would be needed? How could enough MAR allowance be made available? What would be the cost?
- What are the pros, cons, and costs of Pu-238 options?
- Are modules needed, or are other options preferable?
- The FY2014 National Defense Authorization Act permits NNSA, once certain conditions have been met, to build two modules. One module of 5,000 sf could take on most of the Pu-238 MAR from PF-4 and would free up about 5,000 sf in that building. Would the additional freed-up MAR and space permit PF-4 to fabricate 80 ppy? If so, would there be a need for a second module? What would be the cost of the first module? Would a second module cost less?
- How much space and MAR would AC for 80 ppy require?
- What are the pros, cons, and costs of having SRS or LLNL perform some AC?
- What would it cost to convert RLUOB to HC-3? What would be the adverse consequences if RLUOB were operated as is with 1,000 g of WGPu?

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Manufacturing Nuclear Weapon “Pits”: A Decisionmaking Approach for Congress

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Congressional Research Service

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Pit

- Fissile core of a nuclear weapon
- Uses plutonium
- Detonates the secondary (main) stage
- No pit, no weapon

Manufacturing Capacity

- Cold War: up to 2,000 pits per year (ppy)
  - Rocky Flats Plant halted ops in 1989
- Current capacity: ~10 ppy
- DoD requirement: 80 ppy
  - Support some Life Extension Programs
  - Hedge against unanticipated pit problems
  - Hedge against geopolitical risk
  - Some question the need for 80
    - A separate debate
    - This presentation addresses how to reach 80
    - If 80 becomes seen as plausible, debate over number needed becomes more important

A Sisyphean History

- Many facilities proposed since 1989
  - SNML, Complex 21, MPF, CNPC, Complex 2030, CMRR-NF
  - None succeeded
  - Some were built and torn down!
    - NMSF, Building 371
  - No new plutonium processing facilities have been brought online since 1978 (PF-4)
- Problems
  - Cost growth
  - Schedule slippage
  - Capacity >> need
  - Shoddy design or construction

What’s Needed to Manufacture 80?

- Manufacturing tasks
  - Pit fabrication, material prep, material control and accountability, quality control, waste mgmt, etc.
  - These all entail Material At Risk (MAR) and space
    - MAR: radioactive material that an event could release
    - Space: laboratory floor space suitable for ops
- Need sufficient margin
  - Margin: space available for mfg minus space required for mfg; same for MAR
  - Margin must *always* be >0
    - Margin can change over time

Calculating Margin: Is There Enough?

- Critical question for Congress
- Need 4 numbers:
  - 1. MAR available for mfg
  - 2. MAR required for mfg
  - 3. Space available for mfg
  - 4. Space required for mfg
  - These numbers can change over time
- 1 and 3 are available
- 2 and 4 have not been calculated rigorously for 80 ppy
  - Congress could request them

Key Decision 1 for Congress

- If there is not enough margin for space and MAR for 80 ppy, how can it be provided?

Margin and Uncertainty

- $\text{Margin}_{\text{space}} = \text{Available}_{\text{space}} - \text{Required}_{\text{space}}$
- $\text{Margin}_{\text{MAR}} = \text{Available}_{\text{MAR}} - \text{Required}_{\text{MAR}}$
- These produce static, point-in-time numbers
  - Zero uncertainty
- But uncertainties may creep in over time, affecting availability and requirements for MAR and space
  - Examples
    - Requiring more ppy increases demand for space, MAR
    - Seismic concerns may reduce available MAR
    - Removing unneeded Pu from PF-4 may increase available MAR
  - More examples follow

Uncertainties, over Decades, May Alter Space and MAR Required and Available for Pit Mfg

	Factors	Example 1	Example 2	Example 3	Example 4
1	Factors increasing supply (availability) of MAR	Develop means to increase PF-4 seismic resilience	Clean out PF-4 vault, store more Pu needed for ongoing work in vault	Remove unneeded plutonium	New interpretation of a regulation permits increased MAR
2	Factors reducing supply (availability) of MAR	A previously unknown seismic fault is discovered at TA-55	New interpretation of a regulation tightens restrictions	New regulation	DNFSB raises concern about an existing procedure
3	Factors increasing supply (availability) of space	More efficient use is made of PF-4 basement, freeing lab space	Build modules	Clean out and repurpose rooms in PF-4	Add shielding around gloveboxes, permitting closer spacing
4	Factors reducing supply (availability) of space	Add non-pit mission in PF-4	Pit manufacture uses more equipment than previously thought	A new regulation requires increasing space between gloveboxes to reduce dose	Contamination from an accident prevents use of a room in PF-4 for some time
5	Factors increasing demand (requirements) for MAR	Requirement changed to 125 ppy because of geopolitical developments	Faster process exposes more MAR	Partial collapse shuts CMR; its plutonium is moved to PF-4	Problem in a deployed weapon brings more pits to PF-4 for analysis
6	Factors reducing demand (requirements) for MAR	Requirement changed to 40 ppy because pit reuse proves more applicable than expected	Place more plutonium in highly robust containers	Develop lower-MAR manufacturing processes	Move Pu-238 mission out of PF-4
7	Factors increasing demand (requirements) for space	Requirement changed to 125 ppy because pit surveillance reveals unexpected pit problems	Workload for processing drums containing plutonium waste abruptly increases	A new manufacturing layout increases throughput but uses more space	Pit Disassembly and Conversion workload increases
8	Factors reducing demand (requirements) for space	Requirement changed to 40 ppy because plutonium is found to age more slowly than previously thought	Use 2 or 3 shifts per day	A new layout that minimizes space is designed	Some AC equipment is moved from PF-4 to RLUOB

Source: CRS. Green = factors increasing margin; red = factors reducing margin.

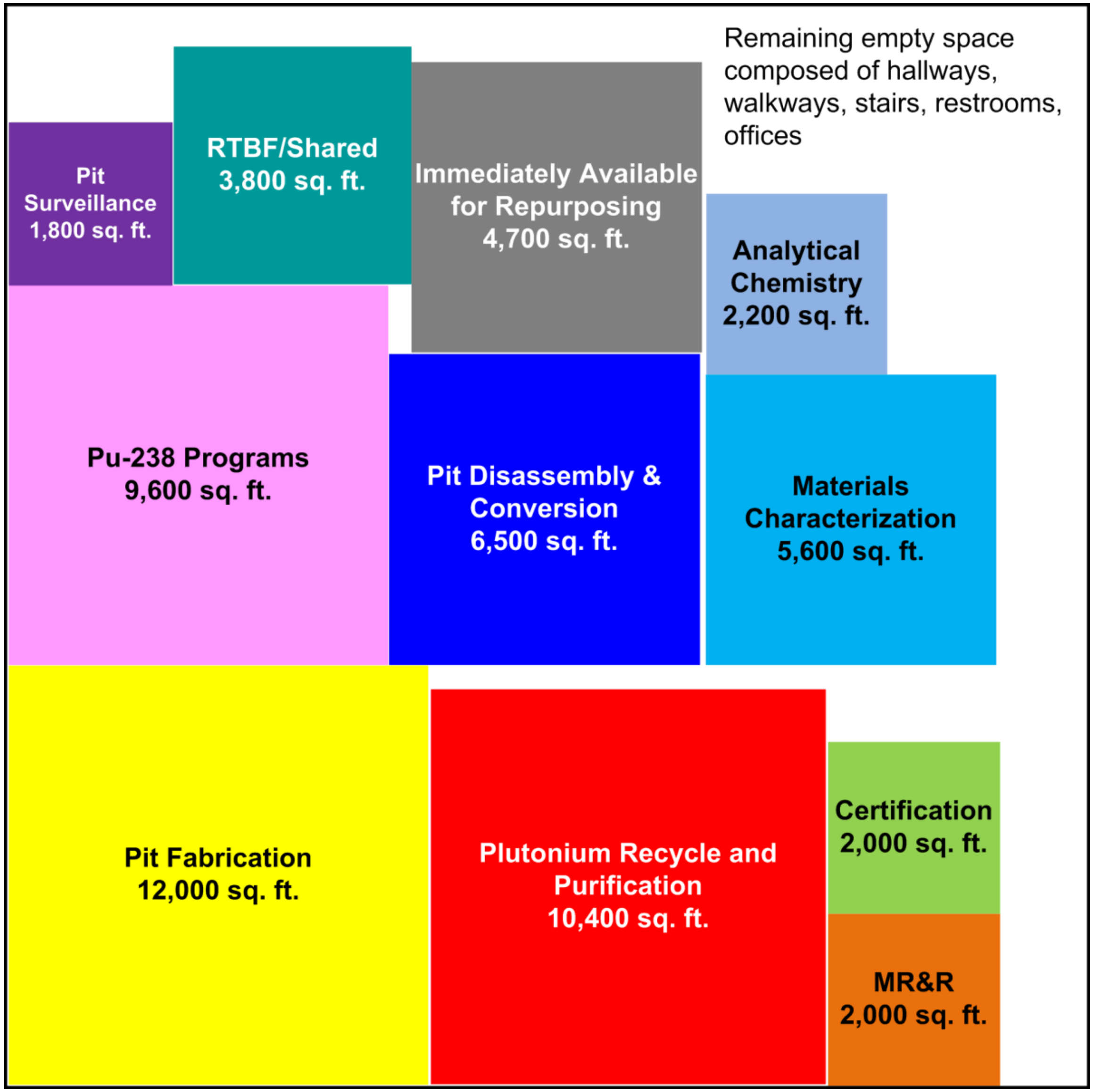
Key Decision 2 for Congress

- Once enough margin is provided for space and for MAR, how can it be maintained over decades despite uncertainties?

Space: Providing and Maintaining Sufficient Margin

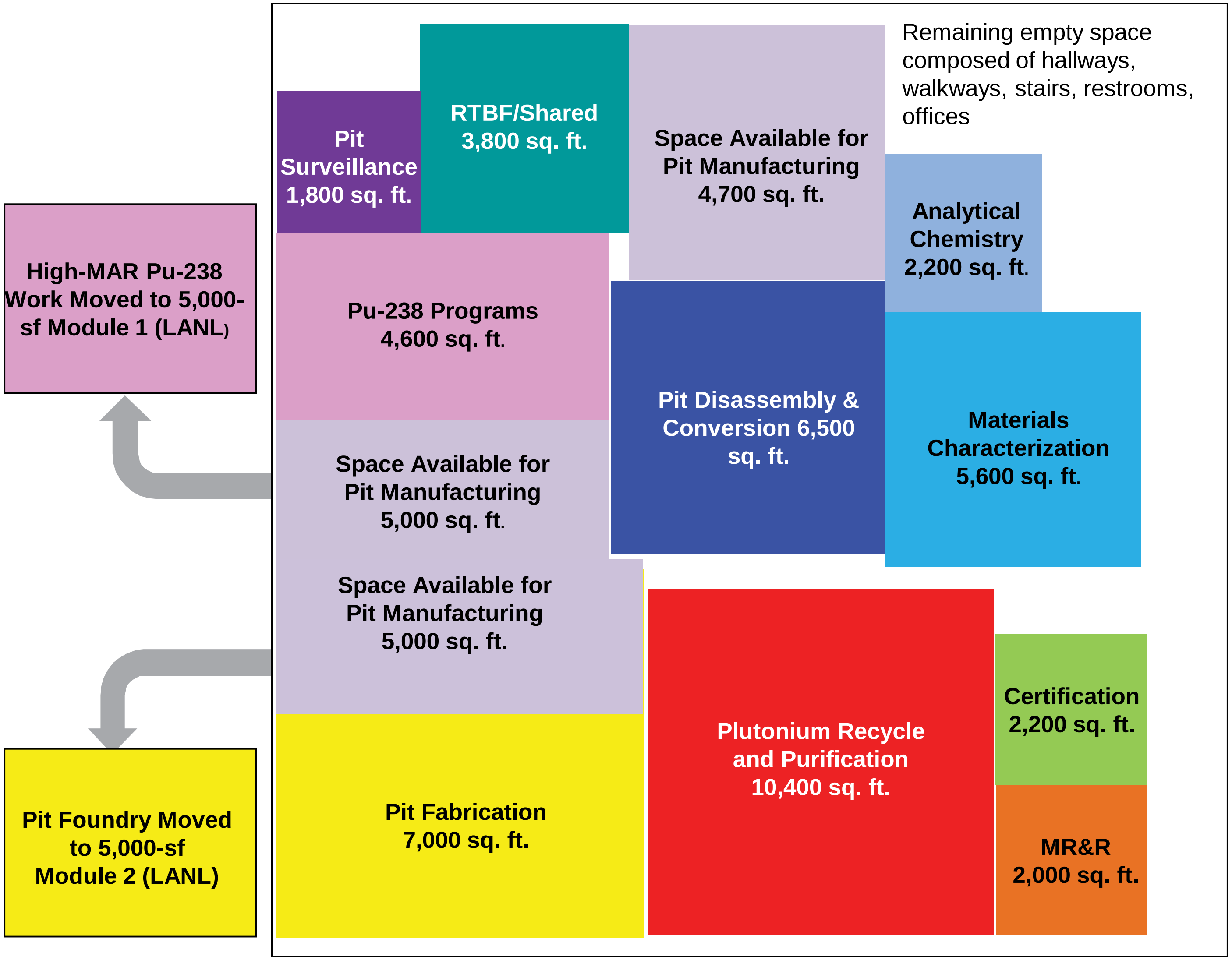
- Essential if current space margin is insufficient
- May be needed if uncertainties materialize that reduce space margin
- Focus is on PF-4 (Plutonium Facility 4)
  - Main plutonium building at Los Alamos National Laboratory (LANL)
  - Only building that can currently make pits
  - Nation’s only remaining multi-program, multi-function, plutonium processing facility
- Various construction/non-construction options
  - Implement some promptly, hold others in reserve

1. PF-4 Space Allocation as of Early 2012



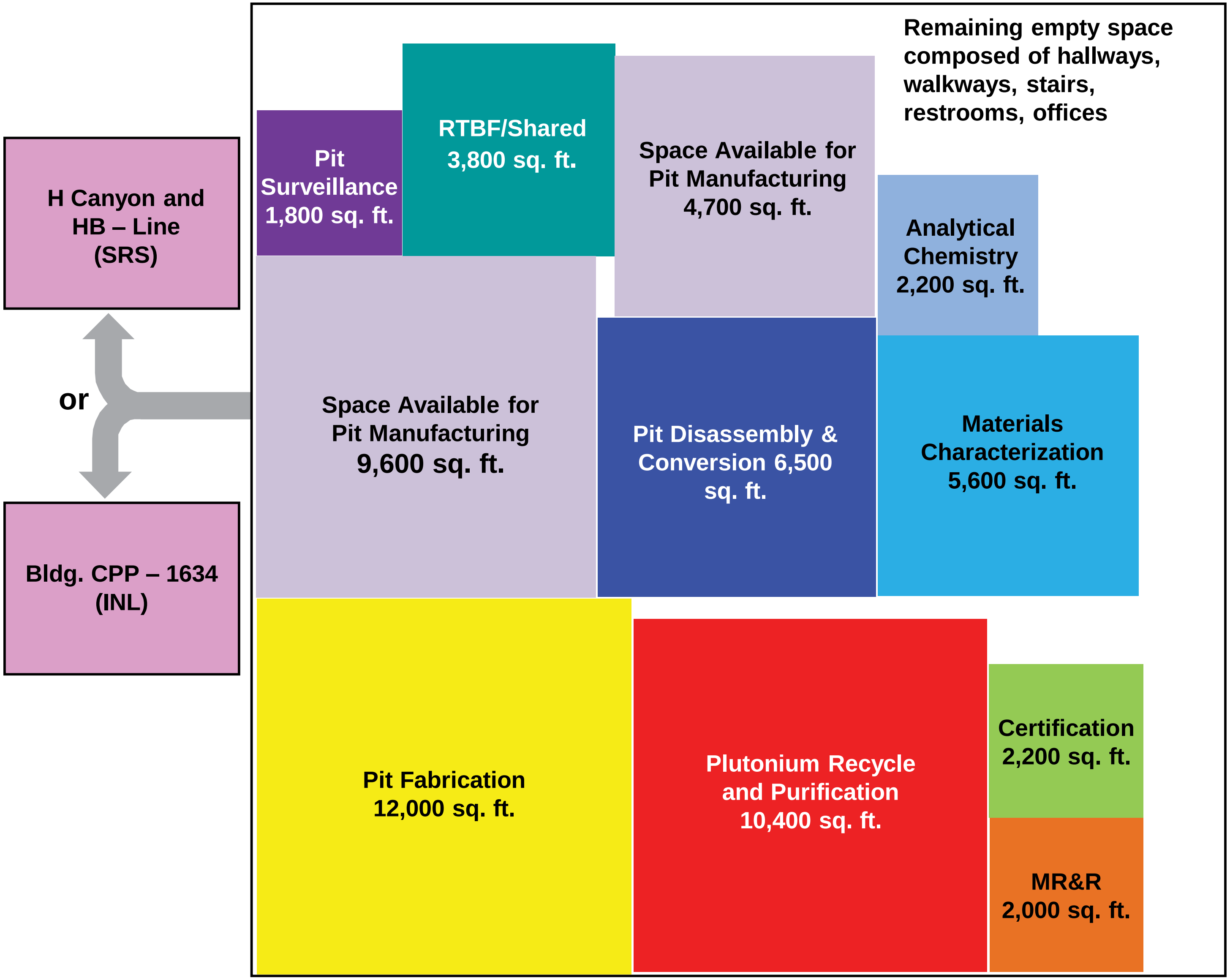
Source: Los Alamos National Laboratory. The blocks in this diagram represent space allocations to scale, but do not show the physical location of each activity within PF-4.

2. Releasing Space in PF-4 with Two Modules



Source: Base graphic, Los Alamos National Laboratory, modifications by CRS. The blocks in this diagram represent space allocations to scale, but do not show the physical location of each activity within PF-4.

3. Releasing Space in PF-4 by Moving Pu-238 Offsite



Source: Base graphic, Los Alamos National Laboratory, modifications by CRS. The blocks in this diagram represent space allocations to scale, but do not show the physical location of each activity within PF-4.

Increasing Space Margin in PF-4 for Mfg without Major Construction (Examples)

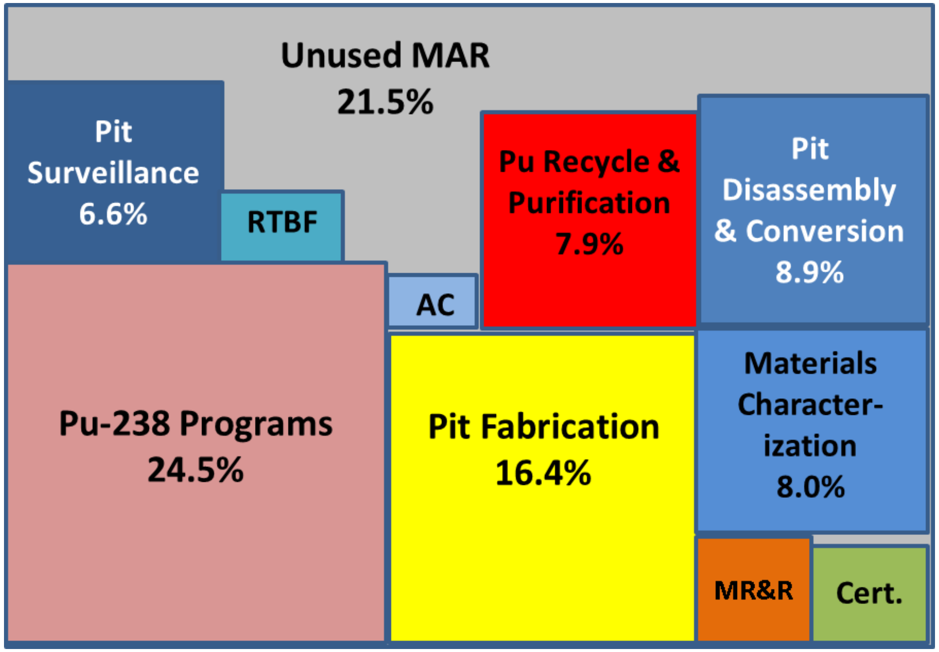
- Design a more space-efficient work flow
- Develop equipment for faster throughput
  - Need fewer pieces of equipment
- Repurpose unused space or space used for lower-priority programs
- Make better use of basement
- Move some eqpt to other buildings or sites
- Use 2 or 3 shifts per day

MAR: Providing and Maintaining Sufficient Margin

- Essential if current MAR margin is insufficient
- May be needed if uncertainties materialize that reduce MAR margin
- Focus is on PF-4
- Various construction/non-construction options
  - Implement some promptly, hold others in reserve
- Note: MAR margin and space margin are separate

1. PF-4 MAR Usage by Program on 2/27/2013

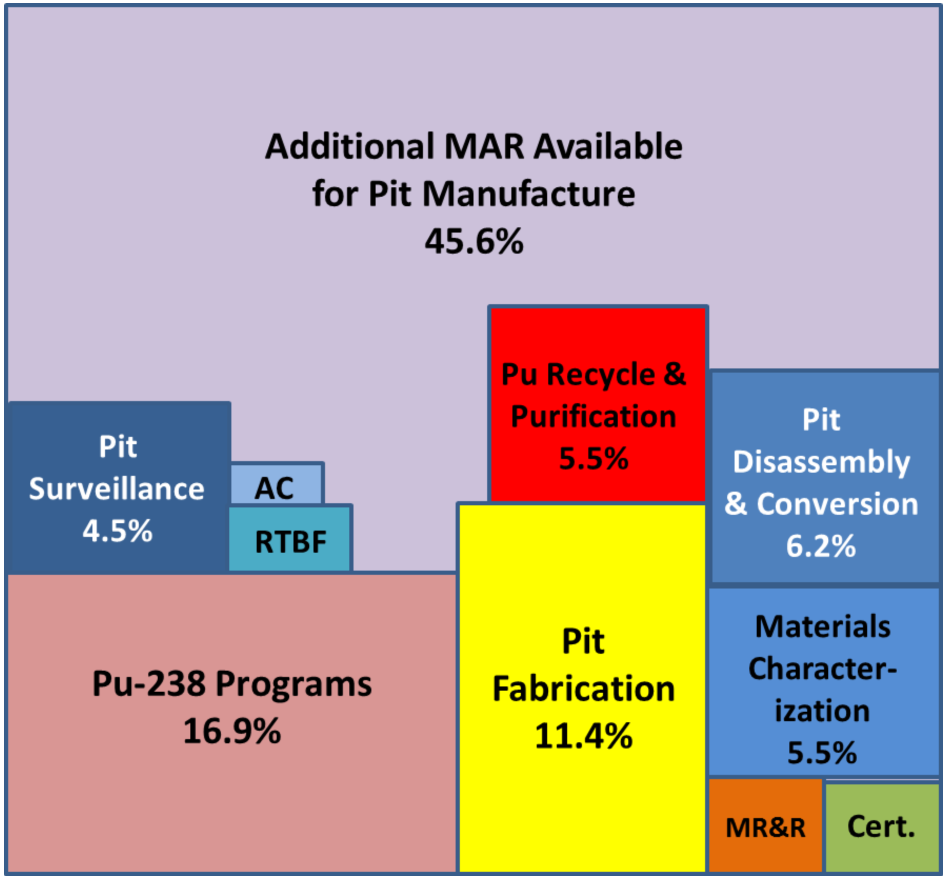
Units in this graphic are kilograms of plutonium, not area
MAR allowance for this configuration is 1,800 kg of plutonium



Source: Los Alamos National Laboratory. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4.

2. PF-4 MAR with Seismic Upgrades

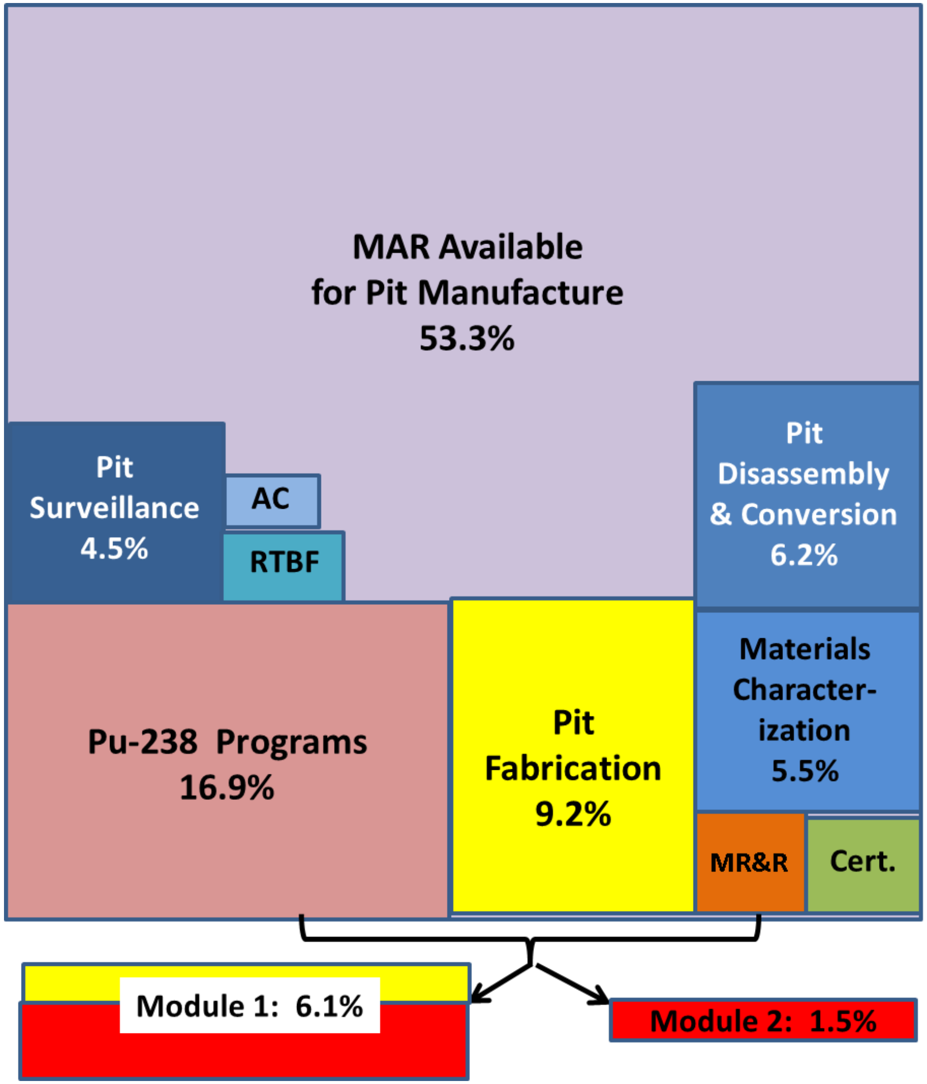
Units in this graphic are kilograms of plutonium, not area
MAR allowance for this configuration is 2,600 kg of plutonium



Source: Data provided by Los Alamos National Laboratory, graphic by CRS. MAR available for pit manufacturing in this and the next two Figures has increased because seismic upgrades permit a substantial increase (here assumed to be 44%) in PF-4 MAR. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4.

3. PF-4 MAR with Two Modules

Units in this graphic are kilograms of plutonium, not area
MAR allowance for PF-4 for this configuration is 2,600 kg of plutonium

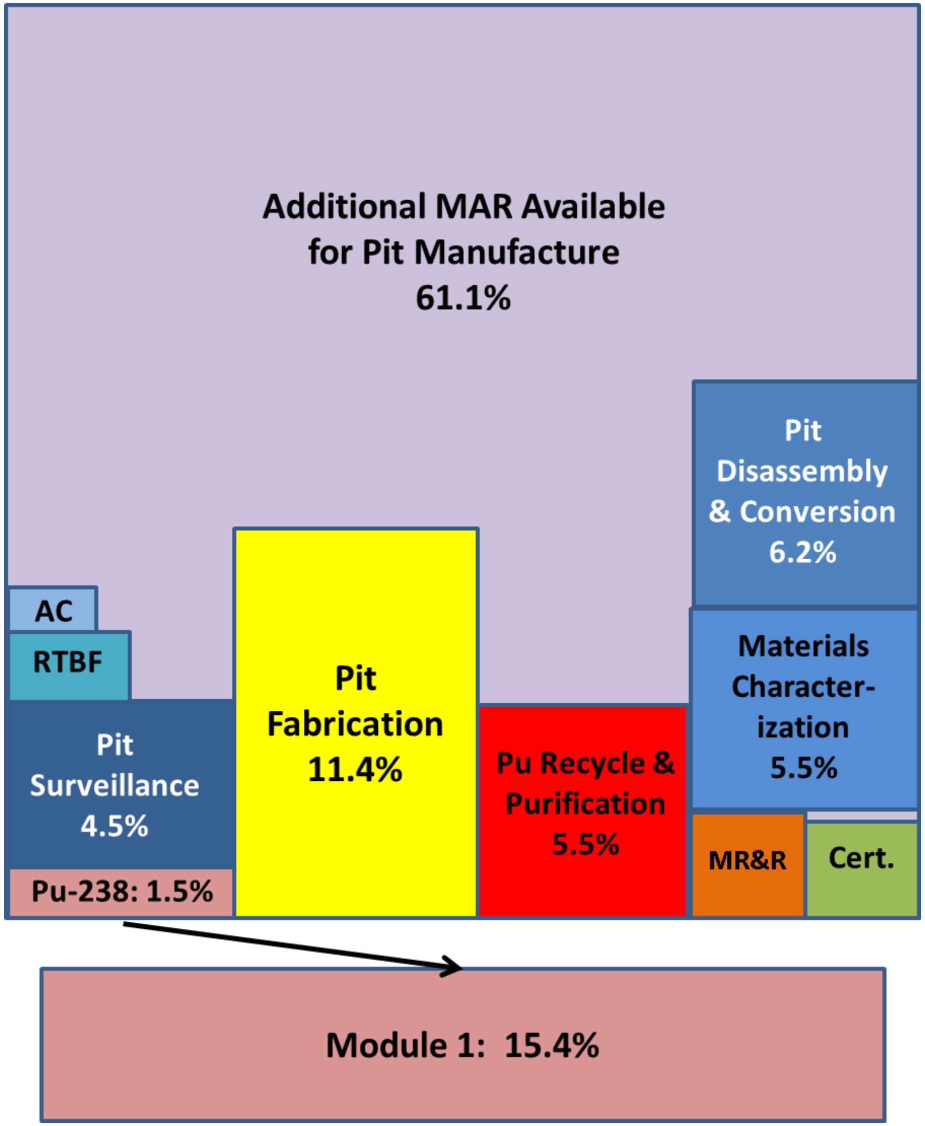


Source: Data provided by Los Alamos National Laboratory, graphic by CRS. Red blocks are Plutonium Recycle and Recovery, which in this Figure is moved from PF-4 to external modules. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4.

4. PF-4 MAR with One Module

Units in this graphic are kilograms of plutonium, not area

MAR allowance for PF-4 for this configuration is 2,600 kg of plutonium



Source: Data provided by Los Alamos National Laboratory, by CRS. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4.

Increasing MAR Margin in PF-4 without Major Construction (Examples)

- Strengthen PF-4 seismically
  - Wrap columns; shear walls; reinforce ceiling; drag strut
  - These reduce the risk of PF-4 collapse in a design basis earthquake

Photo: Google Maps. Photo shows PF-4 roof with drag strut circled.

- Reduce risk of PF-4 collapse releasing Pu
  - Install rugged containers in production areas
  - Remove tons of combustible material from PF-4
  - Anchor gloveboxes more strongly to floor

Notional Decision Sequence for Downselecting Pit Manufacturing Options

Options	A	B	C	D	E	F	G	H	I	J
Enough MAR?	YES	NO	YES	NO	YES	YES	NO	NO	YES	YES
Enough space?	NO	NO	YES	YES	YES	YES	NO	YES	YES	NO
Feasible set			C		F	E			I	
Cost ($B)			1.5		1.4	0.9			8.3	
Affordable?			YES		YES	YES			NO	
Feasible and affordable set			C		F	E				
Compare against other criteria			fair		excellent	poor				
Final selection					PROCEED					

Source: CRS. Note that MAR, space, cost, and other criteria may change over time, and that every item in this graphic, including cost figures, is notional.

Without data on MAR and space requirements, can’t know which MAR and space options provide sufficient margin!

No changes may be needed, or

Non-construction options may suffice, or

Major construction may be required

Analytical Chemistry (AC)

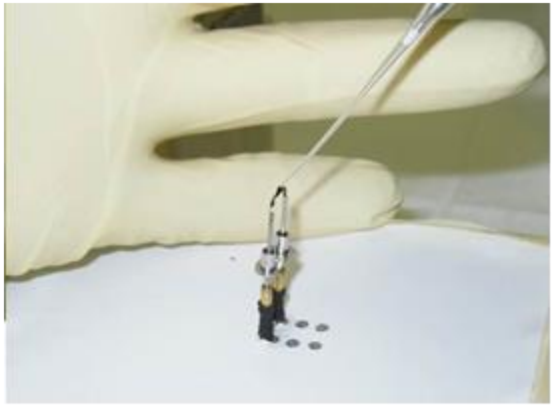


Photo: Los Alamos National Laboratory

- An essential part of mfg
  - Analyzes multiple samples of Pu from each pit
  - Uses little MAR and much more space per unit MAR than mfg
- Margin not at issue
  - Complex made up to 2,000 pits/yr, has excess AC capacity
  - AC can be done at multiple sites (SRS, LLNL)
    - Questions of cost, current capacity, required refurbishment

Must Consider AC Issues Other Than Margin

- Problem: CMR (1952) does AC now, must close (2019?)
- LANL will maintain all AC *capabilities;* issue is *capacity*
- Amount of AC capacity to be kept at LANL depends on:
  - How much AC *can* LANL conduct?
    - Depends on space and MAR of buildings, esp. RLUOB
  - What fraction of total AC *should* LANL conduct?
    - **Most:** Maintain LANL as center of Pu expertise; lower cost; avoid shipping Pu; use other sites for surge
    - **Part:** Distribute expertise; backup; cross-check accuracy; peer review of results; no advantage to LANL in doing AC for 80 vs. 40

Facility Alternatives for AC

- RLUOB with 26g MAR
- RLUOB with 1000g MAR

Photo: Los Alamos National Laboratory

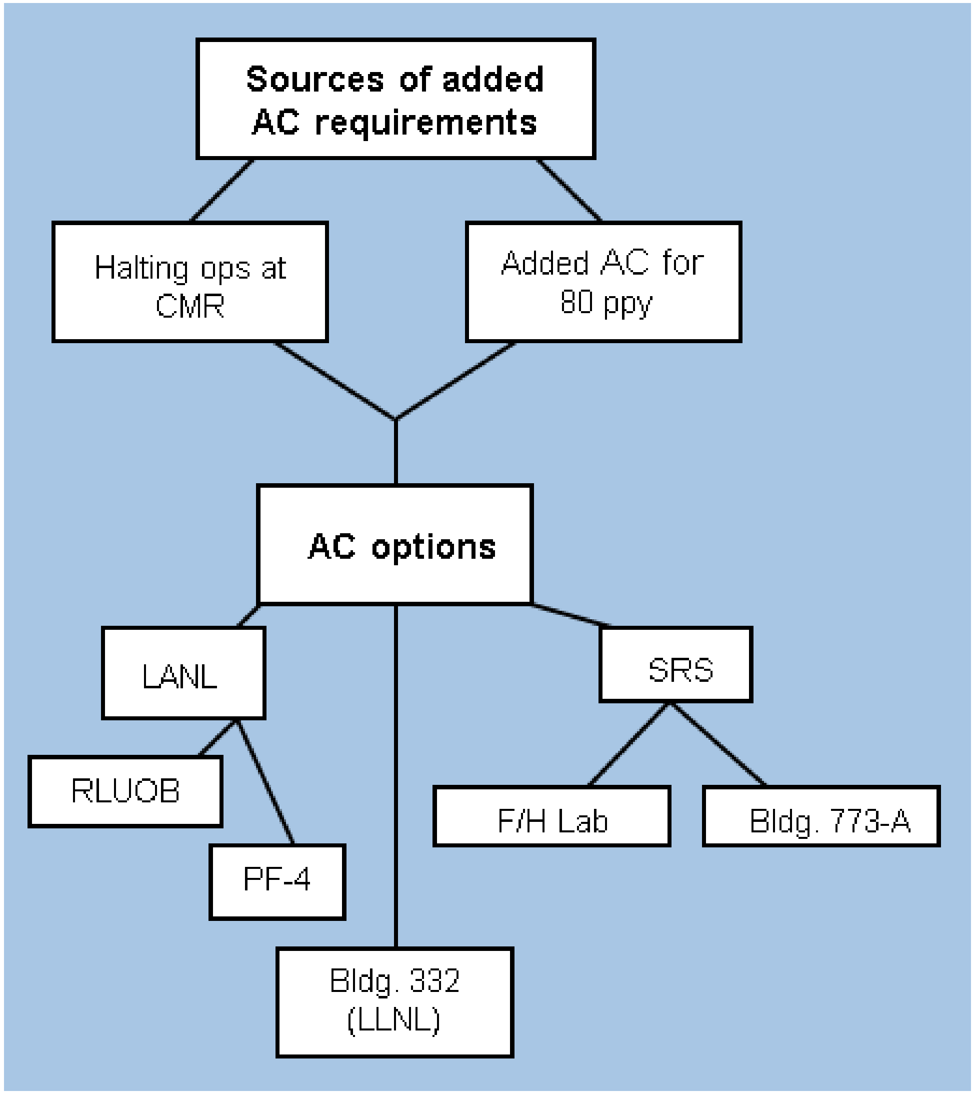
- LLNL Building 332
- SRS F/H Lab
- SRS Bldg. 773-A

Photo: Lawrence Livermore National Laboratory

Photo: Savannah River Site

Photo: Savannah River Site

Analytical Chemistry: Requirements and Options to Support 80 ppy



Source: CRS

Key Decision 3 for Congress

- How much AC at LANL, how much at other sites?

Wrapup

- **One question for Congress**
  - Is there enough MAR and space margin for 80 ppy?
- **Need two numbers to find out**
  - How much space is required to manufacture 80?
  - How much MAR is required to manufacture 80?
- **Three decisions for Congress**
  - If there is not enough space and MAR margin to manufacture 80 ppy, how to provide it
  - Once enough margin is provided, how to maintain it over decades despite uncertainties
  - How much AC at LANL vs. other sites

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Manufacturing Nuclear Weapon "Pits": A Decisionmaking Approach for Congress

Jonathan E. Medalia
Specialist in Nuclear Weapons Policy

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CRS REPORT
Prepared for Members and
Committees of Congress

Summary

A "pit" is the plutonium "trigger" of a thermonuclear weapon. During the Cold War, the Rocky Flats Plant (CO) made up to 2,000 pits per year (ppy), but ceased operations in 1989. Since then, the Department of Energy (DOE) has made at most 11 ppy for the stockpile, yet the Department of Defense stated that it needs DOE to have a capacity of 50 to 80 ppy to extend the life of certain weapons and for other purposes. This report focuses on 80 ppy, the upper end of this range.

Various options might reach 80 ppy. Successfully establishing pit manufacturing will require, among other things, enough laboratory space and "Material At Risk" (MAR). MAR is essentially the amount of radioactive material permitted in a building that could be released in an accident; there must be enough MAR available for manufacturing within the MAR "ceiling." PF-4, the main plutonium building at Los Alamos National Laboratory (LANL), or other structures would house manufacturing. Analytical chemistry (AC), which analyzes the composition of samples from each pit to support manufacturing, will also require availability of MAR and space.

For an option to support 80 ppy, MAR and space available for manufacturing and AC must exceed MAR and space required for 80 ppy. "Margin" is the amount by which an available amount exceeds a required amount. This report presents amounts of MAR and space potentially available for manufacturing under several options, though they may require updating. Calculation of margin—needed to determine if an option passes a minimum test for feasibility—also requires data on MAR and space required for 80 ppy, yet these data have never been calculated rigorously. As a result, it is not known if an option would increase capacity too little (making an option infeasible), too much (making an option too costly), or by an appropriate amount. Congress could direct the National Nuclear Security Administration, which operates the nuclear weapons program, to provide data on space and MAR required to manufacture 80 ppy. These data would permit calculation of space margin and MAR margin as static numbers. However, the situation is dynamic: uncertainties may materialize over time, increasing or decreasing margin.

AC poses different issues. It is needed to support production. It requires much space but uses little MAR. The nuclear weapons complex has ample excess space and MAR available for AC, so margin is not at issue, though such factors as logistics might become an issue.

Thus, three key decisions face Congress in deciding how to produce 80 ppy:

- **Decision 1:** For pit manufacturing, is there currently enough margin for space and MAR in PF-4? If not, what can be done to provide it?
- **Decision 2:** Once enough margin for space and margin for MAR are provided for pit manufacturing, what steps can be taken to maintain these margins over decades in the face of uncertainties?
- **Decision 3:** How much AC should be done at LANL, what is needed to make the space and MAR at LANL sufficient to support that amount of AC, and how much, if any, AC should be done at other sites?

Choosing among options also requires data on how options compare on cost and other metrics, setting up a process for downselection.

This report is best viewed in color, as it contains many multicolored graphics.

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Background

Congress has been deeply involved for decades in setting policy, providing funding, and supporting or rejecting programs for the nuclear weapons enterprise. For example, it established the National Nuclear Security Administration (NNSA), a semi-autonomous component of the Department of Energy (DOE) that manages the nuclear weapons program; established the Nuclear Weapons Council, a joint NNSA-Department of Defense (DOD) agency that coordinates nuclear weapons programs; rejected a major facility to manufacture a key nuclear weapon component; initiated and later rejected the Reliable Replacement Warhead; and directed NNSA, the Government Accountability Office, and others to conduct studies on nuclear weapon issues.

One issue of longstanding concern to Congress is the production of "pits." A pit is a nuclear weapon component, a hollow plutonium shell that is imploded with conventional explosives to create a nuclear explosion that triggers the rest of the weapon. While U.S. policy is not to build new-design nuclear weapons for new missions, some argue that the capacity to manufacture new pits may be needed to extend the service life of certain existing weapons, to replace pits in deployed weapons that develop pit problems unexpectedly, and to hedge against possible geopolitical surprises.

During the Cold War, the Rocky Flats Plant (CO) manufactured as many as 2,000 pits per year (ppy). On June 6, 1989, armed agents from the Federal Bureau of Investigation and the Environmental Protection Agency raided Rocky Flats to investigate suspected environmental crimes.[1] As a result, DOE first suspended pit production at Rocky Flats later that year, subsequently halted it permanently, and eventually dismantled the plant and remediated the site.

With Rocky Flats closed, Congress and the Administration searched for many years for a way to make pits. NNSA proposed a two-track strategy. In one track, Plutonium Facility 4 (PF-4), the main plutonium building at Los Alamos National Laboratory (LANL) (NM), would house a pilot plant to develop pit production processes and manufacture a small number of pits. It took until 2007 for LANL to make its first "war reserve" pits, i.e., those certified for use in the stockpile. In that year, LANL made 11 such pits, the highest number since 1989.[2]

The second track involved a facility with the capacity to make pits on an industrial scale, on the order of 100 or more ppy. Several facilities were proposed, as described in "A Sisyphean History: Failed Efforts to Construct a Building to Restore Pit Production," in CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*. None came to fruition. For example, in the FY2006 budget cycle, Congress eliminated funding for the Modern Pit Facility, which was to have a capacity between 125 and 450 ppy, and in its FY2013 budget request the Administration "deferred" a facility that would have conducted operations in support of pit production "for at least five years." That facility appears unlikely to proceed. Indeed, PF-4, which opened for operations in 1978, is the last U.S. plutonium processing building to come online.

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[1] "Feds Raided Rocky Flats 25 Years Ago, Signaling the End of an Era," by Electa Draper, Denver Post, June 1, 2014, http://www.denverpost.com/news/ci_25874064/feds-raided-rocky-flats-25-years-ago-signaling.

[2] Information provided by Los Alamos National Laboratory, email, November 13, 2013.

As of June 2014, NNSA had the *capacity* to manufacture about 10 non-war reserve pits per year in PF-4. (War reserve (WR) pits are those judged acceptable for use in the nuclear stockpile. Other pits are manufactured for such purposes as development or process qualification.) However, with most work at PF-4 halted in June 2013, the actual manufacturing *rate* in June 2014 was zero for pits of any type; work is resuming at the end of June 2014. Further, the *capacity* to manufacture WR pits was zero: since there was no requirement to manufacture WR pits, some processes needed to certify pits as WR had been suspended after the previous WR build of W88 pits was completed in FY2011. NNSA anticipates manufacturing a few pits a year in the near future to prepare to manufacture WR pits.

The schedule for ramping up pit production is uncertain. A Department of Defense (DOD) official stated in 2013 that "there is no daylight between the Department of Energy and the Department of Defense on the need for both a near-term pit manufacturing capacity of 10 to 20 and then 30 by 2021, and then in the longer term for a capacity of 50 to 80 per year."[3] Also in 2013, a National Nuclear Security Administration (NNSA) document stated, "Preliminary plans call for pit production of potentially up to 80 pits per year starting as early as FY 2030."[4] In 2014, an NNSA document changed the date for achieving a 30-ppy capacity to "by 2026,"[5] and a 2014 Department of Energy (DOE) document stated, "Current plans call for pit production capability of 50-80 pits per year by FY 2030."[6] Also, Section 3114 of the FY2015 defense authorization bill, H.R. 4435, as passed by the House, would require NNSA to produce 30 WR pits per year during 2023, at least 50 during 2026, and to demonstrate for at least 90 days during 2027 the ability to manufacture WR pits at a rate of 80 per year.

Some favor a capacity of greater than 80 ppy, while others argue that a lower number would suffice.[7] That debate is beyond the scope of this report, which focuses on how to achieve a capacity of 80 ppy because that is the high end of DOD's range. While 80 ppy has been beyond reach for a quarter-century, the debate over that capacity would take on added salience to the extent that it moves within the realm of feasibility.

Congress remains deeply involved in efforts to increase pit production capacity. As noted above, Section 3114 of H.R. 4435, the FY2015 defense authorization bill as passed by the House, sets a schedule for production of WR pits. Section 3133 directs NNSA to submit "a report containing an analysis of using or modifying existing facilities across the nuclear security enterprise" to support NNSA's plutonium strategy. In its report on S. 2410, the FY2015 defense authorization bill, the Senate Armed Services Committee directed NNSA to include construction of modules (described

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[3] Testimony of Andrew Weber, Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, in U.S. Congress. Senate. Committee on Armed Services. Subcommittee on Strategic Forces. *Hearing to Receive Testimony on Nuclear Forces and Policies in Review of the Defense Authorization Request for Fiscal Year 2014 and the Future Years Defense Program*, April 17, 2013, p. 15.

[4] U.S. Department of Energy. National Nuclear Security Administration. *Fiscal Year 2014 Stockpile Stewardship and Management Plan,* Report to Congress, June 2013, page 2-22. NNSA is the separately-organized component of the Department of Energy that is responsible for operating the U.S. nuclear weapon program.

[5] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2015 Congressional Budget Request.* Volume 1, National Nuclear Security Administration, DOE/CF-0096, March 2014, p. 64, http://www.energy.gov/sites/prod/files/2014/03/f12/Volume_1_NNSA.pdf.

[6] U.S. Department of Energy. *Fiscal Year 2015 Stockpile Stewardship and Management Plan,* report to Congress, April 2014, page 2-6, http://nnsa.energy.gov/sites/default/files/nnsa/04-14-inlinefiles/2014-04-11%20FY15SSMP_FINAL_4-10-2014.pdf.

[7] For detail on these arguments, see the section "Pit Production Capacity: How Much Is Needed?," in CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*, by Jonathan E. Medalia

later), which would support an exit from a 1950s-era plutonium building at LANL by 2019, as a separate line item in the FY2016 budget "to add additional visibility into the process."[8] The House Appropriations Committee recommended a substantial increase in funding "for a robust experimental effort in fiscal year 2015 to better understand the properties of plutonium and ensure the NNSA can support certification requirements for pit reuse as an option for future [nuclear weapon life extension programs]."[9] Use of retired pits in life extension programs would reduce the number of new pits that would have to be manufactured. The committee also recommended $35.7 million for moving certain activities out of the Chemistry and Metallurgy Research building (described below), which became operational in 1952.

While DOD has a requirement for up to 80 ppy, some key questions about *how* to manufacture at that rate remain not only unanswered but also unasked. These questions involve details about the facilities at LANL and perhaps elsewhere that would fabricate pits and perform supporting tasks. Without answers to these questions, Congress cannot know whether existing buildings, without modifications, could manufacture 80 ppy; or if modest upgrades would suffice; or if major construction would be needed to augment capacity. This report provides a framework for analyzing requirements for manufacturing, details key questions, and raises the possibility that Congress may choose to direct NNSA to generate the data needed to answer them.

Specifically, regardless of what capacity is needed, and when, Congress and the Administration will need to decide among options. This report presents three key decisions and an approach to help structure them. It focuses on two metrics: the amount of two facility resources (laboratory floor space and Material At Risk (MAR), discussed next) available for pit manufacturing. It shows that it is not known whether available amounts suffice. While NNSA has extrapolated space and MAR requirements for manufacturing 80 ppy from much lower numbers, extrapolations set an upper bound and would overstate requirements. As such, they are of questionable value for decisionmaking. Space and MAR requirements for manufacturing 80 ppy have never been calculated rigorously, though they could be. Comparing space and MAR required vs. available would show whether there is enough space and MAR at the moment. Over time, however, various factors will affect availability and requirements. While few of these factors can be predicted, this report discusses ways to offset any adverse effects from them. In addition, decisions will be needed regarding analytical chemistry, which supports pit manufacturing. For background, see CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress;* CRS Report R43428, *U.S. Nuclear Weapon "Pit" Production: Background and Options in Brief,* is a condensed version.

Terminology

Several tasks, terms, and buildings are central to the subsequent discussion.

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[8] U.S. Congress, Senate Committee on Armed Services, *Carl Levin National Defense Authorization Act for Fiscal Year 2015*, Report to accompany S. 2410, 113th Cong., 2nd sess., June 2, 2014, S.Rept. 113-176 (Washington: GPO, 2014), p. 289.

[9] U.S. Congress, House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 2015*, Report to accompany H.R. 4923, 113th Cong., 2nd sess., June 20, 2013, H.Rept. 113-486 (Washington: GPO, 2014), p. 131.

Tasks

- **Pit manufacturing** involves several tasks. Among other things, pit *fabrication* casts "hemishells" (half-pits) of plutonium, machines them to remove excess material, and welds two together to form a pit. The current pit fabrication line was intended as a pilot plant; its capacity is about 10 ppy. It is being upgraded to reach a capacity of 30 ppy; further upgrades would be needed to reach 80. Pit *manufacturing* also involves such supporting tasks as purifying plutonium for use in pits; certification to ensure that finished pits meet required standards; material control and accountability; waste management; and analytical chemistry. This report uses "fabrication" as a subset of "manufacturing."
- **Analytical chemistry** (AC) is essential for pit manufacturing, but this report considers it separately because it has large space requirements. AC analyzes plutonium samples taken from each pit at various stages in its fabrication. AC determines the isotopic composition of the plutonium and the amount of alloying materials and impurities it contains. Pit fabrication requires extensive AC for every pit. AC supports other pit manufacturing tasks, and non-pit tasks as well, though historically pit fabrication has been the greatest user of AC. The building at Los Alamos National Laboratory (LANL) that currently performs AC to support pit manufacture and many other plutonium tasks is in poor shape and not seismically robust. DOE wants to halt work there by 2019, so one or more other facilities will be needed.

Terms

- **Laboratory floor space**, or "space." Laboratory buildings have space for corridors, offices, etc., but laboratory floor space is where AC, pit fabrication, and other work is done. Space is expressed in units of square feet (sf).
- **"Material At Risk"** (MAR) is "the amount of radioactive materials … available to be acted on by a given physical stress."[10] It is material that could be released by a disaster, such as an earthquake that collapses a building followed by a fire. Each building that works with plutonium has a building-specific MAR allowance. MAR is expressed in units of plutonium equivalent, discussed next.
- **Plutonium** is the fissile material in pits. Four forms are relevant here. *Plutonium-239* (Pu-239) is the fissile isotope in pits. However, pits contain other plutonium isotopes in addition to Pu-239; that mixture is called *weapons-grade plutonium* (WGPu). Since some of the other isotopes are more radioactive than Pu-239, WGPu is about 1.5 times as radioactive as Pu-239. *Plutonium-238* (Pu-238) is 277 times more radioactive than Pu-239. It is used to power space probes and has some military applications, but is not used in pits. It is relevant to pit manufacturing options because 40 percent of the MAR allowance in PF-4 is allocated to Pu-238.[11] Moving some or all Pu-238 work out of PF-4, the main

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[10] U.S. Department of Energy. DOE Handbook: *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities,* Vol. I, Analysis of Experimental Data, DOE-HDBK-3010-94, December 1994, p. xix.

[11] Information provided by Los Alamos National Laboratory, October 23, 2013. Note that MAR *allowance* for a program must at all times be greater than or equal to the actual MAR that the program is using.

plutonium building at LANL, would make MAR and space available for other purposes. In PF-4, MAR is measured in units of *plutonium equivalent* (PE), which is about 1.38 times as radioactive as Pu-239; this measure is linked to potential dose if plutonium is released, such as by an earthquake and fire.

Buildings

- **PF-4** (Plutonium Facility 4) is the only building in the United States with the combination of attributes required to make pits: high security, pit fabrication equipment, and the ability to handle high-MAR processes. Its current MAR allowance is 1,800 kg PE. It is located at LANL, the nation's "center of excellence" for plutonium, and the only place that has made pits since 1989; as a result, LANL has the scientific, engineering, and craft expertise needed to make pits. PF-4 also performs other tasks involving plutonium. It is the last U.S. plutonium processing facility to be brought online, in 1978, and is the only remaining U.S. multi-program, multi-function plutonium processing facility. It would be about a half-century old when production is anticipated to reach 80 ppy. Within LANL, PF-4 is located in Technical Area (TA) 55.
- The **Chemistry and Metallurgy Research** (CMR) building currently provides AC support for limited pit manufacture and other plutonium tasks in PF-4. Most of it was completed in 1952. It is "genuinely decrepit"[12] and "structurally unsound,"[13] in the words of two studies, and is much more vulnerable to collapse in an earthquake than more recent buildings.[14] Accordingly, "NNSA maintains its commitment to cease programmatic operations in the CMR facility at LANL in approximately 2019."[15]
- The **Radiological Laboratory-Utility-Office Building** (RLUOB, pronounced "rulob") was completed in FY2010. It is configured for AC. NNSA plans that RLUOB would house AC equipment needed to support pit manufacture, and possibly enough to support manufacture of 80 ppy.

An Approach to Decisionmaking

An approach to maintaining confidence in nuclear weapons may help provide lessons for decisionmaking on pits. This section describes that approach, then modifies it to make it applicable to pits.

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[12] William Perry et al., *America's Strategic Posture*, Congressional Commission on the Strategic Posture of the United States, Washington, United States Institute for Peace Press, 2009, p. 50.

[13] Defense Nuclear Facilities Safety Board, "Summary of Significant Safety-Related Infrastructure Issues at Operating Defense Nuclear Facilities," letter report to the Congress, September 10, 2010, p. 1, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Reports%20to%20Congress/2010/sr_20100910_4673.pdf.

[14] For example, Michael Salmon, structural engineer and seismic analyst, Los Alamos National Laboratory, estimates that "collapsing RLUOB [a building completed in FY2010, described below] would take an earthquake with 4 to 12 times more force than an earthquake that would collapse CMR." Information provided December 2013.

[15] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2015 Congressional Budget Request,* Volume 1, National Nuclear Security Administration, DOE/CF-0096, March 2014, p. 213, http://www.energy.gov/sites/prod/files/2014/03/f12/Volume_1_NNSA.pdf.

Quantification of Margins and Uncertainties (QMU)

In 1992, the United States began a moratorium on nuclear testing that continues to the present.[16] Concurrent with the moratorium, the United States developed and implemented a stockpile stewardship program to maintain nuclear weapons without testing. An issue became how to demonstrate confidence in the safety and reliability of these weapons. One approach, developed by LANL and Lawrence Livermore National Laboratory (LLNL), was Quantification of Margins and Uncertainties, or QMU.[17] The idea underlying QMU was that several steps in a nuclear weapon—transmission of a signal to detonate the weapon, explosion of the high explosive surrounding the pit, transmission of the energy from the explosion of the primary stage to the secondary stage, and detonation of the secondary stage—must all work for the weapon to function.[18] Each step, or "gate" in QMU terminology, can be quantified. For example, a certain amount of energy must be transmitted to the secondary for it to detonate. Another QMU concept is margin. If the minimum amount of energy needed to detonate the secondary is X, and the amount of energy predicted to be transmitted to the secondary is 3X, then there is a margin of 2X, i.e., margin is the amount by which the predicted quantity exceeds the minimum required quantity. At the same time, there are uncertainties in the predicted quantity. Did the calculation incorporate all relevant variables? Were there biases in experiments on which the calculations were based? Were the most relevant nuclear tests used as a data source? The uncertainty can be quantified through calculations (such as computer models); further, the amount of uncertainty is bounded because each gate has an upper and a lower limit. If margin exceeds uncertainty for a particular gate, then there can be confidence that the weapon will "pass through" that gate satisfactorily, and if margin exceeds uncertainty for all gates, there can be confidence that the weapon will work. The degree of confidence at each gate is expressed as margin divided by uncertainty; the higher the number, the greater the confidence.

Maintaining Margin by Developing Means to Offset Uncertainties

QMU provides three key concepts relevant to decisionmaking on pit manufacturing.

- **Margin,** in this case, is the amount by which (1) space available for pit manufacturing exceeds (2) space required to manufacture 80 ppy, and the amount by which (3) MAR available for pit manufacturing exceeds (4) MAR required to manufacture 80 ppy. (The two margins are independent.) Thus, solving for margin requires four numbers. Figures 1-7 show items (1) and (3) under various scenarios. Regarding items (2) and (4), LANL has examined space and MAR needed to fabricate 80 ppy in a preliminary fashion, but has not performed a detailed analysis of the full pit manufacturing process, including plutonium supply, waste management, AC, external support activities, and fabrication.[19] To enable calculation of margin, Congress would need to obtain two numbers:

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[16] This report uses "nuclear testing" to mean underground nuclear explosions producing a nuclear yield. Other tests are done to nuclear weapons, their materials, and components that do not involve a nuclear yield.

[17] For a detailed discussion of QMU, see National Research Council, Division on Engineering and Physical Sciences, committee on the Evaluation of Quantification of Margins and Uncertainties Methodology for Assessing and Certifying the Reliability of the Nuclear Stockpile, *Evaluation of Quantification of Margins and Uncertainties: Methodology for Assessing and Certifying the Reliability of the Nuclear Stockpile,* Washington, National Academies Press, 2009, 79 p.

[18] The primary stage consists of the pit, high explosives, and other materials. Its detonation sets off the secondary stage.

[19] Information provided by Los Alamos National Laboratory, April 29, 2014.

  - Space required to manufacture 80 ppy, and
  - MAR required to manufacture 80 ppy.

  In addition, available space and MAR figures would probably need to be updated. Once those numbers are provided, Congress would be in a better position to determine which options would free enough space and MAR in PF-4 to manufacture 80 ppy, or if there is already sufficient space and MAR in PF-4. LANL (and perhaps other sites) has computer models and other resources needed to perform these calculations. AC also has space and MAR requirements but, as discussed in "Options for Analytical Chemistry," margins are not at issue because the nuclear weapons complex has ample space and MAR for AC for 80 ppy.

- **Uncertainty:** Margins can change over time. While MAR and space margins could be calculated precisely for the present moment, they cannot be calculated in advance because many actions, events, decisions, and discoveries have the potential to create uncertainties that could increase or decrease availability of, or requirements for, space and MAR, thus increasing or decreasing margin. **Figure 1** shows hypothetical examples of uncertainties: those in red could reduce margin, and those in green could increase it. The longer the timeframe, the more uncertainties can be expected to emerge. While the *effects* of these uncertainties on pit manufacturing can be calculated once they materialize, the *likelihood* that they will come into being, and even the type of uncertainties—in contrast to the uncertainties in QMU—cannot be predicted or bounded, let alone quantified. Another means of maintaining margin, not shown in **Figure 1**, is for Congress or NNSA to bar from PF-4 new missions that would consume MAR and space, especially those that could be placed elsewhere.
- **Maintaining margin despite uncertainties:** It would not be acceptable to let uncertainties that materialize into actual events reduce margin below zero, as that could force a halt to pit manufacturing. One way to maintain enough margin to support a specified pit manufacturing capacity in the face of uncertainties is to develop multiple means to counterbalance uncertainties that would reduce margin. Some means could be implemented promptly; others could be developed, held in reserve, and implemented only as needed. Having these means available for future deployment would add confidence that sufficient margin could be maintained.

Figure 1. Uncertainties May Alter Space and MAR Required and Available for Pit Manufacturing over Decades

Hypothetical Actions, Events, Decisions, and Discoveries Could Reduce or Increase Margin in PF-4

	Factors	Example 1	Example 2	Example 3	Example 4
1	Factors increasing supply (availability) of MAR	Develop and install means to increase PF-4 seismic resilience	Clean out PF-4 vault, store more plutonium needed for ongoing work in vault	Remove unneeded plutonium	New interpretation of a regulation permits increased MAR (as with RLUOB)
2	Factors reducing supply (availability) of MAR	A previously unknown seismic fault is discovered at TA-55	New interpretation of a regulation tightens restrictions	Cracks in concrete from an earthquake reduce confidence in PF-4	Defense Nuclear Facilities Safety Board raises concerns about an existing procedure
3	Factors increasing supply (availability) of space	More efficient use is made of PF-4 basement; some lab operations are moved there	Build modules	Clean out and repurpose rooms in PF-4	Add shielding around gloveboxes, permitting more in a room
4	Factors reducing supply (availability) of space	Add non-pit mission in PF-4	Pit manufacture uses more equipment than previously thought	A new regulation requires increasing space between gloveboxes to reduce dose	Contamination from an accident prevents use of a room in PF-4 for some time
5	Factors increasing demand (requirements) for MAR	Requirement changed to 125 ppy because of geopolitical developments	Faster process exposes more MAR	Partial collapse shuts CMR; its plutonium is moved to PF-4	Problem in a deployed weapon brings more pits to PF-4 for analysis
6	Factors reducing demand (requirements) for MAR	Requirement changed to 40 ppy because pit reuse proves more applicable than expected	Place more plutonium in highly robust containers	Develop lower-MAR manufacturing processes	Move Pu-238 mission out of PF-4
7	Factors increasing demand (requirements) for space	Requirement changed to 125 ppy because pit surveillance reveals unexpected pit problems	Workload for processing drums containing plutonium waste increases abruptly	A new manufacturing layout increases through-put but uses more space	Pit Disassembly and Conversion workload increases
8	Factors reducing demand (requirements) for space	Requirement changed to 40 ppy because plutonium is found to age more slowly than previously thought	Use 2 or 3 shifts per day	A new layout that minimizes space is designed	Some AC equipment is moved from PF-4 to RLUOB

Source: CRS.

Notes: Green boxes, factors increasing margin; red boxes, factors reducing margin.

Determining how much MAR and space would be needed to manufacture 80 ppy would require an industrial process analysis. A study would seek to determine what equipment would be needed to manufacture 80 ppy; lay out production lines in PF-4 to accommodate that equipment while retaining space needed for other tasks; determine what tasks, if any, could be moved from PF-4 if necessary to accommodate the lines; and calculate what MAR would result from this production line configuration. An extrapolation provides an upper bound: LANL is planning to increase PF-

4's capacity to 30 ppy, and if a given amount of space and equipment can make 30 ppy, then three times those amounts could make 90 ppy. However, such a study is likely to find that less space and equipment would suffice because of efficiencies. In a process step, for example, a piece of equipment that could support manufacture of 300 ppy would suffice for any number less than 300, whether 10, 30, or 80. A study would need to take into account that there are many ways to make more space or MAR available and to reduce space or MAR requirements, thereby increasing margin, as discussed under "Space Options for PF-4" and "MAR Options for PF-4." This detailed analysis would be needed to determine whether enough MAR allowance and space could be made available in PF-4 to manufacture 80 ppy. Given that margin can change over time, it might be useful to have an annual review of margin and potential factors that could affect it.

Which organization could perform such a study? Candidates include LANL, another lab or plant in the nuclear weapons complex, NNSA, DOD, or an independent group like the National Academy of Sciences or the JASON defense advisory group. Since LANL is intimately familiar with PF-4, it could be argued that it should do the report. On the other hand, LANL could be perceived as having a conflict of interest. An independent group would not have this potential conflict of interest but would not have LANL's knowledge of PF-4. To address this dilemma, LANL might conduct the initial study and an independent group could review it. Another approach would be to have the study prepared jointly by LANL and Lawrence Livermore National Laboratory (LLNL), or prepared by LANL and peer-reviewed by LLNL. LANL and LLNL are both nuclear weapon design laboratories, so LLNL's expertise would be of use in evaluating a LANL study. Since the two labs have often competed for projects and have a reputation as "friendly adversaries," involving LLNL would provide an added measure of confidence in the study.

Before the study could begin, the Nuclear Weapons Council would need to define key parameters:

- What capacity is being sought? Is it 80 ppy, or 50 with a surge capacity to 80, or 80 with a surge capacity to 125, or something else?
- What operating tempo is planned? Would manufacturing use 1 shift per day/5 days a week, 2 shifts per day/5 days a week, or operate 24/7? The answer is related to capacity. If the capacity sought is 80 ppy using 3 shifts per day, a higher surge capacity would be difficult at best. The answer is also related to cost and equipment. Using two shifts per day, it might be possible to reach 80 ppy with equipment that would support 50 ppy on a single shift; a more costly option would be to increase the amount of equipment (and thus floor space used) to enable production of 80 with a single shift.
- Would the capacity be held in standby mode most of the time, available for use as needed; operated for months or years at 80 ppy for certain pit campaigns and held in low-rate production mode for other periods; operated at a steady rate, less than 80, to level out the workload between periods when no pits are needed and periods when 80 ppy are needed; or operated at full capacity at all times?
- What programs could be moved out of PF-4 if necessary to create enough space or MAR, where would they go, what would the move cost, and who would pay?
- What is a reasonable tradeoff between cost and capacity? As a notional example, if LANL could manufacture 70 ppy using existing buildings and an operating cost of $500 million per year, but it would cost $2 billion for new construction and $700 million in annual operating cost to manufacture 80 ppy, would the

added capacity be worth the added cost? A sensitivity analysis would provide the data, but the answer would be a matter of judgment.

- It appears that it would take over a decade to reach 80 ppy, and the path to that capacity is obscure. If the path becomes clearer, it would become more important to determine if 80 is the right number, or if it should be higher or lower.

This report starts with a static approach to pit manufacturing, examining the space and MAR margins for 80 ppy once current projects in PF-4 that will increase permitted MAR and make more space available are completed. This static approach provides a baseline and metrics to indicate whether margin is ample, minimal, or insufficient, and to judge the impact of future deviations from this baseline. Next, the report takes a dynamic approach, noting that uncertainties could affect margin and how they might be offset. Finally, it considers analytical chemistry requirements. This approach leads to three decisions Congress may choose to consider:

- **Decision 1:** For pit manufacturing, is there currently enough margin for space and MAR in PF-4? If not, what can be done to provide it?
- **Decision 2:** Once enough margin for space and margin for MAR are provided for pit manufacturing, what steps can be taken to maintain these margins over decades in the face of uncertainties?
- **Decision 3:** For AC, space and MAR available across the nuclear weapons complex exceed space and MAR required by a considerable amount, so margin is not an issue. Instead, the issue is how much AC should be done at LANL and how much, if any, AC should be done at other sites?

Requirements for Pit Manufacturing

The floor layout to manufacture 30 ppy would fully consume the space, and most of the MAR allowance, currently available in PF-4. As a result, manufacturing 80 ppy would require more space and MAR than are currently available for that task in PF-4. Further, updated seismic modeling results raised concerns that an earthquake might collapse or otherwise compromise the building,[20] forcing a reduction in PF-4 MAR from 2,600 kg PE to 1,800 kg PE. However, LANL is undertaking several projects that would increase the MAR permitted in PF-4. Various projects

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[20] "In public comments at a Capitol Hill Club event this summer [2013], DNFSB member Jack Mansfield explained the Board's concerns. The [PF-4] facility, built in the late 1970s, is 'brittle,' Mansfield said. 'It was discovered after this facility was built that large buildings, to be survivable in serious earthquakes, have to have a bit of ductility. It was also discovered after the Loma Prieta earthquake that round columns, if accelerated up into the plywood they support, crumble. Those two vulnerabilities were identified early, but they're not built into PF-4.'

"He added: 'The result is that there is a probability, albeit small, that the building could collapse, with great loss of life within and with dispersal of plutonium.' Previous upgrades were based on calculations that did not fully characterize the problems facing the facility, Mansfield said. Those calculations were 'very good' and 'did a lot,' Mansfield said, but 'the problem is that any of the columns, crushed like the ones on the highway did—the whole roof would go down like a zipper.'" Todd Jacobson, "DOE Says Alternate Analysis of PF-4 Seismic Risks Will Be Done in Dec.," *Nuclear Weapons & Materials Monitor,* September 6, 2013, http://www.lasg.org/press/2013/NWMM_6Sep2013.html.

Also, the Defense Nuclear Facilities Safety Board (DNFSB) stated: "DOE and the National Nuclear Security Administration (NNSA) have made progress in addressing a number of these [seismic] safety issues, but the Board remains concerned that PF-4 is vulnerable to seismic collapse for the seismic hazard at LANL." Letter from DNFSB to the Congress of the United States, July 15, 2013, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Reports%20to%20Congress/qr__22406.pdf.

to increase seismic robustness have been underway for years; see the section "Increasing MAR Margin Without Major Construction." They proceed on an open-ended basis guided by results of continuing analyses. Once some additional upgrades are completed, PF-4's MAR allowance may revert to 2,600 kg or perhaps some other number. This analysis assumes a MAR allowance of 2,600 kg PE and, as noted in the sidebar, uses space data from 2012.

LANL points out that PF-4, as the only U.S. building that is currently able to make pits, is essential to the entire nuclear weapons enterprise: no PF-4, no pits, no LEPs that require new pits. PF-4 is limited in space and MAR. The MAR limit is somewhat flexible, as various measures can increase it. Similarly, space within PF-4 may be shifted from one purpose to another, and LANL is undertaking such projects, e.g., decontaminating some rooms in PF-4 that are no longer in use and "repurposing" them to make them available for pit manufacture or other uses. However, the space limit is absolute: 60,000 sf of laboratory space. If manufacturing 80 ppy requires more space than is available in PF-4, NNSA would need to find alternatives, whether building modules, moving some tasks to other sites, or reducing capacity to whatever the available space could accommodate.

Which MAR and Space Data to Use?

Space available in PF-4 changes from year to year. A project may be completed, so its rooms may become available; a project may consolidate space, making one of several rooms available; another project may need to add a new instrument or process, requiring more space; or a project may increase or decrease its throughput, altering its MAR. **Figure 2** uses space data provided by LANL for PF-4 as of early 2012, while **Figure 3** and **Figure 4** show options that modify space usage. Actual MAR changes from hour to hour, depending on which operations are in progress. Most operations in PF-4 were suspended in June 2013 and as of mid-June 2014 had not fully resumed. **Table 1**, which also uses data supplied by LANL, shows MAR used by programs on February 27, 2013, i.e., before the suspension. Future MAR and space numbers are likely to differ from those presented here. Different numbers would produce different results in terms of which options are feasible, but would not alter the analytic approach of this report.

It would be difficult for Congress to decide how to obtain the space and MAR for manufacturing 80 ppy without knowing whether there will be sufficient MAR and space margins for 80 ppy. This section considers options that might make the needed space and MAR available. Note that while margin must always be greater than zero, the amount of available space and MAR needed to maintain margin could expand or contract depending on whether required space and MAR expand or contract. For example, MAR insufficient for 80 ppy might suffice for 40 ppy.

Space Options for PF-4

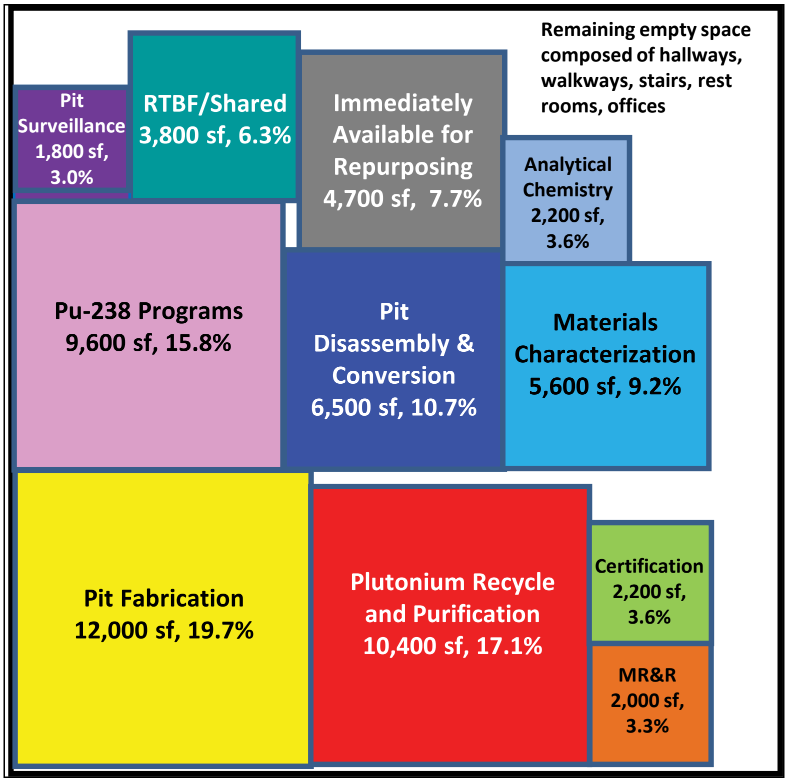
Various options could make more space available in PF-4 for pit manufacture. Some might require major construction; others might not. Sufficient space to manufacture 80 ppy might even be readily available within PF-4 with little or no work. Options would vary in terms of their projected cost and schedule. Some might be implemented quickly and at low cost; others might take longer and cost more. Still others that would entail high cost and long leadtime could be studied (e.g., design work on modules) to determine whether they are feasible and, if so, to facilitate possible future deployment. Any option could be deployed promptly or held in reserve. Thus, for each, a decision would be needed on whether to proceed and, if so, when. Such decisions would depend on how much space was needed given then-current space availability and, later, on the extent of any reduction in space margin. This analysis also applies to "MAR Options for PF-4," below, and is not repeated there.

Making More Space Available Through Major Construction

Figure 2 shows the 2012 allocation of space in PF-4 by program. The gray area, 4,700 square feet (sf), is available for immediate repurposing. It consists of laboratory rooms not currently in use. White areas represent non-laboratory space. Pit fabrication occupies 12,000 sf.

Figure 2. Space Allocation in PF-4

by Program or Activity



Source: Los Alamos National Laboratory.

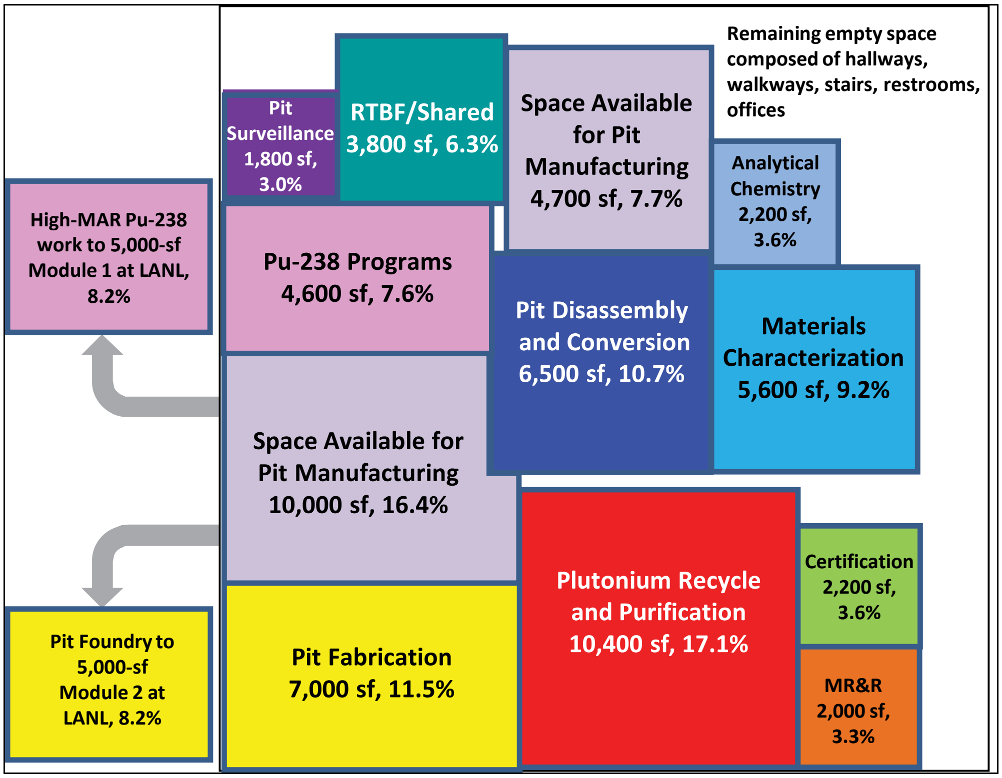
Notes: PF-4 is approximately 280 feet on a side. The blocks in this diagram represent space allocations to scale but do not show the physical location of each activity within PF-4. Figures for square feet (sf) and percentages are for laboratory floor space. The **Appendix** describes each task shown in this and subsequent figures.

One option involves building one or more "modules," reinforced-concrete structures that would be buried near PF-4 and connected to it by a tunnel. Preliminary concepts envision that each module would be roughly 5,000 sf of laboratory space, and that modules would be designed for high-MAR tasks, such as casting plutonium into hemishells or working with Pu-238.

Figure 3 shows how moving these two tasks into two modules could release space in PF-4. It shows 5,000 sf being moved from Pu-238 programs to Module 1, with the released space used for pit manufacturing; another 5,000 sf being moved from pit fabrication space in PF-4 to Module 2, making that much more net space available for pit manufacturing; and the 4,700 sf of space immediately available for repurposing also being used for pit manufacturing, adding 14,700 sf in PF-4 and Module 2 for pit work, with pit fabrication space plus other space made available for pit manufacturing totaling 26,700 sf. (Space for some other tasks, such as Plutonium Recycle and Purification, would also support pit manufacturing.) LANL maintains that a key advantage of modules is that they would permit expansion of capacity on an as-needed basis rather than trying to build a "big box" plutonium building that would attempt to accommodate all foreseeable future needs, an approach that has been rejected for several big-box buildings over many years. Others respond that modules could be costly and, if existing buildings can be used, may not be needed.

Another option (not shown) would be to build one module for Pu-238 work or pit casting. This option would release some 5,000 sf in PF-4 in addition to the 4,700 sf available for repurposing.

Figure 3. Releasing Space in PF-4 by Using Two Modules



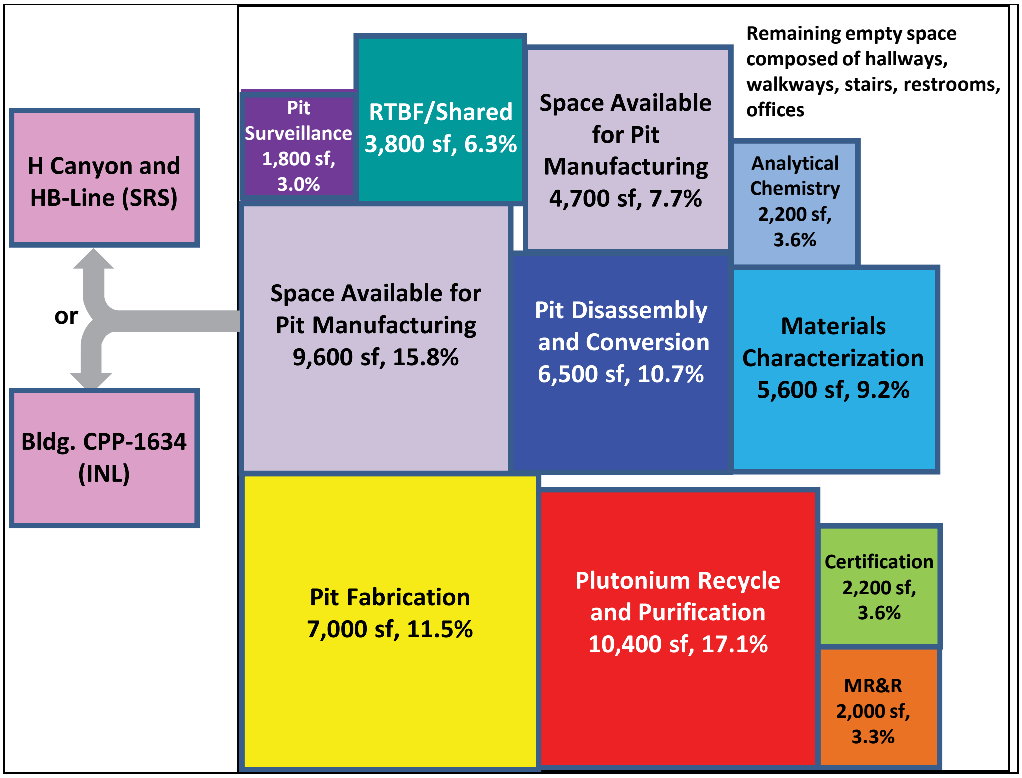
Source: Base graphic by Los Alamos National Laboratory, modifications by CRS.

Note: The blocks in this diagram represent space allocations to scale but do not show the physical location of each activity within PF-4. Modules (external to PF-4) are to same scale as PF-4.

A third option would move Pu-238 work from LANL. Two sites, Savannah River Site (SRS) (SC) and Idaho National Laboratory (INL), have worked with Pu-238 and have stated that they

have, or could modify, buildings to do this work. **Figure 4** shows this option permitting the full amount of space used for Pu-238 in PF-4, 9,600 sf, to be made available for pit manufacturing, as well as the 4,700 sf of repurposable space. This option would result in 26,300 sf for pit work in PF-4. In determining the feasibility of this option, NNSA would need to evaluate space and MAR at other sites, as well as the costs—the move itself, repurposing PF-4 space, refurbishing, reequipping, and staffing the new facility, and so on—of the move.

Figure 4. Releasing Space in PF-4 by Moving Pu-238 Work Offsite



Source: Base graphic by Los Alamos National Laboratory, modifications by CRS.

Note: The blocks in this diagram represent space allocations to scale but do not show the physical location of each activity within PF-4. The space in the block labeled "Space Available for Pit Manufacturing, 9,600 sq. ft." is made available by moving all Pu-238 work to INL or SRS. The blocks for INL and SRS are not to scale, as a detailed study would be required to determine how much space at either site would be needed to accommodate activities that currently occupy 9,600 sf in PF-4.

A fourth option to release space would be to build one or more modules for lower-MAR activities now housed in PF-4, such as materials characterization, which occupies 5,600 square feet of laboratory space, and a gas gun,[21] which occupies another 1,200 square feet of lab space. Moving out these two activities would release about 6,800 square feet of PF-4 lab space, 11 percent of the total. Some waste processing activities in PF-4 are also lower-MAR. While these activities have a lower MAR level, they would still require Hazard Category 3-level facilities. LANL expects these modules would be comparable in cost to Hazard Category-2 modules.[22]

LANL calculates that the current 12,000 sf in PF-4 available for pit fabrication is enough to fabricate 30 ppy once certain upgrades have been completed.[23] However, the space needed for 80

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[21] A gas gun shoots a metal projectile into a piece of plutonium to study how the latter behaves under impact.

[22] Information provided by Los Alamos National Laboratory, July 15, 2014. A Hazard Category (HC) refers to maximum amount of radioactive material (in this case, plutonium) a building can contain. HC-3 buildings can hold 38.6 up to 2,610 grams Pu-239 equivalent; HC-2 buildings, like PF-4, can hold 2,610 grams or more. See "Key Regulatory Terms" in CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*, by Jonathan E. Medalia.

[23] The current capacity of PF-4, with current equipment, is about 10 ppy. However, LANL has embarked on a series of small activities to replace and remove obsolescent equipment and in so doing to reconfigure the space to improve (continued...)

ppy would not increase linearly with capacity. Even calculating the amount of space for equipment is not linear. Each piece of equipment has a specific throughput. If one piece can support 40 ppy, then 80 ppy would require two such pieces, but if one piece suffices to support 30 ppy, then 80 ppy would require three pieces. Adding complexity to the calculation, constraints imposed by room layout, facility layout, and process flows must be considered.

Adding further complexity, determining the space needed for 80 ppy requires analyzing the entire manufacturing process, not just equipment requirements, including answers to such questions as:

- In moving to 80 ppy, how much additional space would be needed in PF-4 for supporting infrastructure, such as packaging, shipping, receiving, waste management, and temporary storage, as well as the material control and accountability needed to send hundreds if not thousands of AC samples annually to LLNL or SRS if those sites are used? Would this latter number be much reduced if the samples were all analyzed at LANL?

- What turnaround time would be required for samples moved onsite or shipped offsite? The time required to receive AC results would be needed in order to estimate the number of gloveboxes and temporary storage locations, and would thus affect space requirements. The analysis would need to take into account that most AC is done on a confirmatory basis, i.e., manufacturing proceeds on the assumption that AC results will confirm that samples are within specifications. (Hemishells not within specifications would be recycled.) Such AC is not time-sensitive. On the other hand, AC to analyze process problems requires fast turnaround to minimize the time the process is shut down. At issue: how much AC is likely to be time-sensitive?

- How much plutonium would pit fabrication need? Increasing the amount of plutonium would require adding electrorefining furnaces, increasing space requirements.

- Since the United States no longer produces plutonium, all U.S. plutonium is "old," such as from retired pits. As plutonium decays, it produces other elements, such as uranium and americium. These must be removed by chemical processes to purify plutonium for use in new pits. (Chemical processes do not remove specific isotopes of plutonium.) PF-4 uses 10,400 sf for plutonium recycle and purification. How much plutonium could that area purify per year? How many ppy would that capacity support? How much more space would be needed to provide plutonium for 80 ppy? Alternatively, could these processes be moved to another site, such as Savannah River Site?

- Pit fabrication generates some plutonium scraps, such as excess material from castings, shavings from lathes, and pits scrapped because they did not meet specifications. Providing for recycle of this plutonium requires space, and producing 80 ppy would require more space than 30. How much space would plutonium disposition require?

(...continued)

operational efficiency. These activities are intended to increase the capacity of the 12,000-sf space to 30 ppy. Information provided by Los Alamos National Laboratory, April 10, 2014.

Increasing Space Margin Without Major Construction

While major construction could make more space available, increasing efficient use of existing space could increase the space margin. This could be done in several ways, such as:

- Designing work flow to minimize space utilization. When DOE decided to move pit manufacture to PF-4, the process line was intended as a pilot plant to develop, quickly, techniques for resuming production. It was not intended as the nation's pit production site; other proposed facilities, such as the Modern Pit Facility, were to fill that role. LANL is currently redesigning the existing pit fabrication space in PF-4 to manufacture up to 30 ppy instead of 10; increased efficiencies of this type would reduce space requirements for 80 ppy, increasing margin.
- Develop equipment and processes for faster work flow so fewer pieces of equipment to manufacture a specified number of pits, reducing floor space.
- Repurpose unused space or space used for lower-priority programs, as discussed.
- Make more efficient use of PF-4's basement, which houses the nuclear materials vault and most utilities, and provides space for shipping and receiving and for staging waste drums. It may be possible to move out some operations from the basement, such as drum storage, freeing space to house such laboratory-floor operations as nondestructive analysis,[24] and some waste management operations.
- Move some equipment out of PF-4. For example, PF-4 houses a gas gun, which propels a metal slug into a plutonium target to study how plutonium behaves under impact. The gas gun uses 1,200 sf of laboratory space in PF-4, and some basement space. Moving it to RLUOB (if that building's MAR were to be increased substantially) or to another site would release space in PF-4.
- Use two or three shifts a day rather than one. So doing would make more intensive use of space by allowing fewer pieces of equipment to produce a given amount of product, thereby reducing space requirements. Rocky Flats Plant, for example, generally operated using three shifts per day. On the other hand, a higher tempo for an extended period could increase operating cost, require more maintenance, reduce time available for maintenance, increase the likelihood of equipment failure, and have more impact on production if equipment fails.

Such options would almost surely be faster and less costly than major construction, but without data on space required for 80 ppy, it is not possible to know if they would provide enough space.

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[24] As an example of nondestructive analysis, radiation detectors can determine the amount of plutonium in a waste drum without opening the drum.

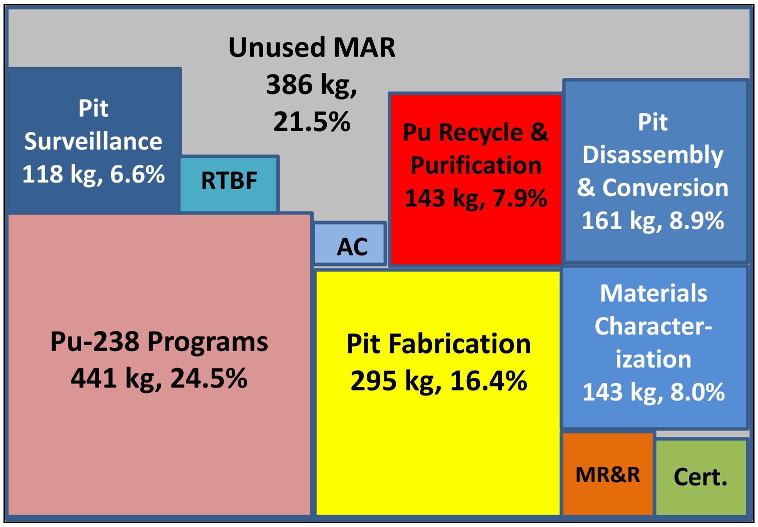
MAR Options for PF-4

Making More MAR Available Through Major Construction

As with space, there are options to provide more MAR. The total MAR allowance for PF-4 on February 27, 2013,[25] was 1,800 kg PE. **Table 1** shows the percentage of the 1,800 kg MAR.

Table 1. PF-4 MAR by Program

Units in this graphic are kilograms of plutonium, not area
MAR allowance for PF-4 for this configuration is 1,800 kg of plutonium
MAR is actual usage on February 27, 2013



	Program	MAR (kilo-grams)	Percent of PF-4 MAR allowance
	PF-4		
🟨	Pit Fabrication	295	16.4
🟪	Unused MAR	386	21.5
🟩	Certification	34	1.9
🟦	Pit Surveillance	118	6.6
🟦	AC	14	0.8
🟦	MC	143	8.0
🟥	Pu-238 Programs	441	24.5
🟦	PDC	161	8.9
🟧	MR&R	38	2.1
🟦	RTBF	26	1.5
🟥	PRP	143	7.9
	Total	**1,800**	**100.0**

Source: Data provided by Los Alamos National Laboratory; graphic by CRS.

Notes: MAR blocks represent, to scale, MAR allocations but not the physical location, form, or material type within PF-4. Detail may not add to total due to rounding. The **Appendix** explains the programs in PF-4.

Abbreviations: AC, Analytical Chemistry; MC, Materials Characterization; MR&R, Materials Recycle and Recovery; PDC, Pit Disassembly and Conversion; PRP, Plutonium Recycle and Purification; RTBF, Readiness in Technical Base and Facilities.

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[25] The Director of Los Alamos National Laboratory "paused" programmatic operations in PF-4 on June 27, 2013, in part to address nuclear criticality safety concerns. Letter from Peter Winokur, Chairman, Defense Nuclear Facilities Safety Board, to The Honorable Frank Klotz, Administrator, National Nuclear Security Administration, May 16, 2014, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Letters/2014/ltr_2014516_24391.pdf. (Criticality safety refers to the risk that certain quantities and configurations of fissile material could support a nuclear chain reaction. The chain reaction would not result in a nuclear explosion but would release a flood of neutrons.) While the MAR allowance is fixed, actual MAR changes from day to day while PF-4 is in normal operating status, varying with the work being performed. PF-4 was in operating status on February 27, 2013.

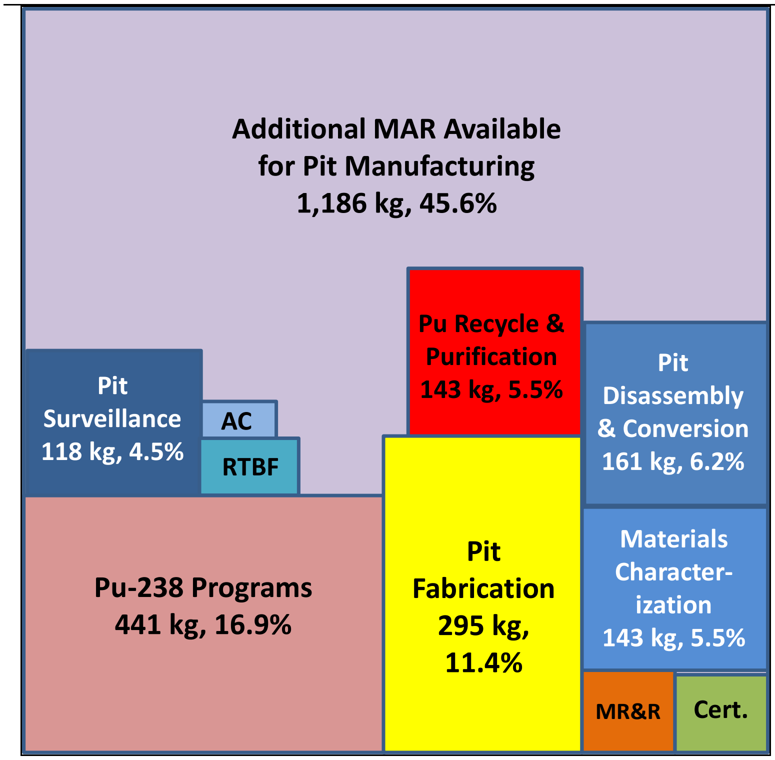
allowance used by each program on that date. For example, Pu-238 work accounted for 24.5 percent of the 1,800 kg PE; pit fabrication, for 16.4 percent; and other tasks, for lesser amounts. The gray space, 21.5 percent, represents the PF-4 MAR allowance unused on February 27, 2013.

As noted, this analysis assumes that seismic upgrades increase PF-4 MAR to 2,600 kg PE. **Table 2** shows that amount of MAR to the same scale as **Table 1** and assumes that programs other than pit manufacturing use the MAR they used on February 27, 2013, for the foreseeable future. It shows that if the newly-available 800 kg PE of MAR and the unallocated MAR are both allocated to pit manufacturing and combined with the pit fabrication MAR, then 57.0 percent of the MAR in PF-4 would be available for pit work. (While the amount of MAR used by other tasks remains the same, the percentage of MAR they use is lower than in **Table 1** because each task accounts for a smaller fraction of the higher MAR allowance.)

Table 2. PF-4 MAR with Seismic Upgrades

Units in this graphic are kilograms of plutonium, not area

MAR allowance for PF-4 for this configuration is 2,600 kg of plutonium



	Program	MAR (kilo-grams)	Percent of PF-4 MAR allowance
	PF-4		
🟨	Pit Fabrication	295	11.4
🟪	AMAPM	1,186	45.6
🟩	Certification	34	1.3
🟦	Pit Surveillance	118	4.5
🟦	AC	14	0.5
🟦	MC	143	5.5
🟥	Pu-238 Programs	441	16.9
🟦	PDC	161	6.2
🟧	MR&R	38	1.5
🟦	RTBF	26	1.0
🟥	PRP	143	5.5
	Total	**2,600**	**100.0**

Source: Data provided by Los Alamos National Laboratory; graphic by CRS.

Notes: This graphic assumes that seismic improvements have raised the MAR allowance back to 2,600 kg, what it was before MAR was reduced due to seismic concerns, and that unallocated MAR is allocated to pit manufacture. MAR blocks represent, to scale, MAR allocations but not the physical location, form, or material type within PF-4. Detail may not add to total due to rounding. The **Appendix** explains the programs in PF-4.

Abbreviations: AC, Analytical Chemistry; AMAPM, Additional MAR Available for Pit Manufacturing; MC, Materials Characterization; MR&R, Materials Recycle and Recovery; PDC, Pit Disassembly and Conversion; PRP, Plutonium Recycle and Purification; RTBF, Readiness in Technical Base and Facilities.

If adding 800 kg of MAR is not sufficient to support 80 ppy, at least three other options would release more MAR. In discussing these options, it is important to recognize that MAR is not spread evenly across PF-4. While Pu-238 is only a small fraction of PF-4's radioactive material by weight, it is so radioactive that it is allocated 40 percent of PF-4's MAR allowance, though it did not use that much on February 27, 2013. Nor is MAR spread evenly within a program space, as discussed below.

Option 1, shown in **Table 3**, would use two modules. Plutonium Recycle and Purification (PRP) uses aqueous (plutonium dissolved in acid) processes and molten processes to recover pure plutonium from scrap or from retired pits by chemically removing impurities.[26] Module 1 would house aqueous processes from PRP, and Module 2 would house molten plutonium from Pit Fabrication and from PRP. (This would eliminate PRP within PF-4.) This option would move about 198 kg of MAR out of PF-4. On a scale using total PF-4 MAR (2,600 kg PE) as 100 percent, Module 1 would have 1.5 percent as much MAR as PF-4 and Module 2 would have 6.5 percent as much. MAR available in PF-4 for pit manufacturing would increase to 62.5 percent.

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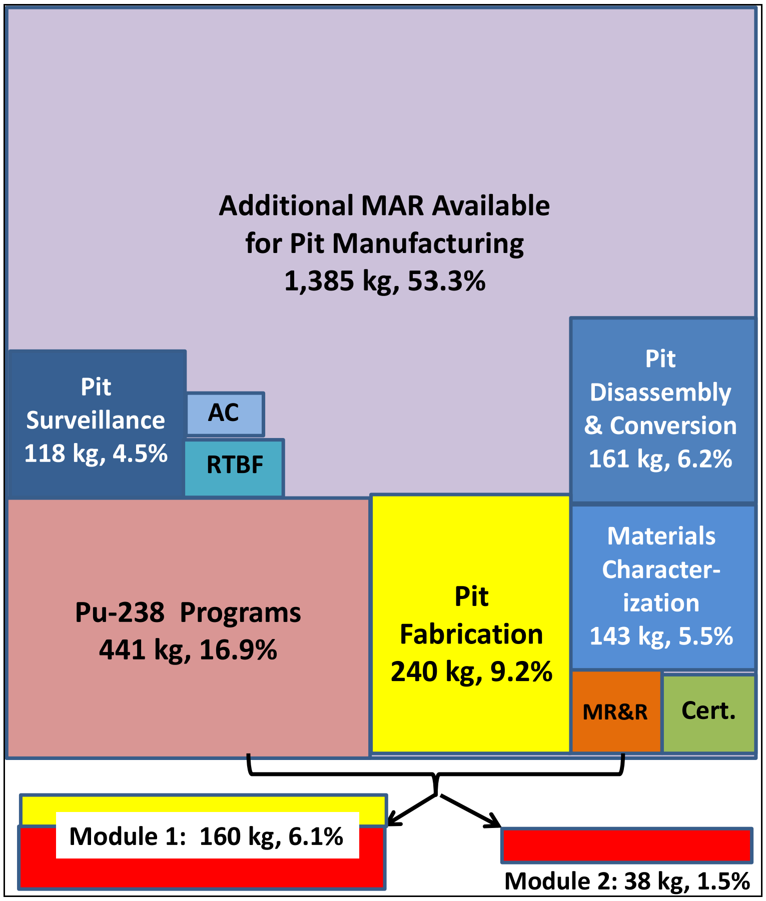
[26] Impurities include americium-241, a decay product of plutonium-239; neptunium-237, a decay product of americium-241; and various uranium isotopes that are decay products of various plutonium isotopes. In addition, some nonradioactive trace elements may have been introduced during previous manufacturing processes. All these would need to be eliminated, or at least reduced below a threshold, for the recovered plutonium to be suitable for use in pits.

Table 3. PF-4 MAR with Two Modules

Units in this graphic are kilograms of plutonium, not area

MAR allowance for PF-4 for this configuration is 2,600 kg of plutonium



	Program	MAR (kilo-grams)	Percent of PF-4 MAR allowance
	PF-4		
🟨	Pit Fabrication	240	9.2
🟪	AMAPM	1,385	53.3
🟩	Certification	34	1.3
🟦	Pit Surveillance	118	4.5
🟦	AC	14	0.5
🟦	MC	143	5.5
🟥	Pu-238 Programs	441	16.9
🟦	PDC	161	6.2
🟧	MR&R	38	1.5
🟦	RTBF	26	1.0
🟥	PRP	0	0.0
	Total	**2,600**	**100.0**
	Module 1		
🟨	Pit Fabrication	55	2.1
🟥	PRP	105	4.0
	Total	160	6.1
	Module 2		
🟥	PRP	38	1.5

Source: Data provided by Los Alamos National Laboratory; graphic by CRS.

Notes: MAR blocks represent, to scale, MAR allocations but not the physical location, form, or material type within PF-4. MAR blocks outside PF-4 (modules) are drawn to the same scale as those inside. Module 1 is for Pit Fabrication (2/3) and Plutonium Recycle and Recovery (1/3); Module 2 is for Plutonium Recycle and Recovery. MAR not used for other programs is assumed to be allocated to pit manufacture. Detail may not add to total due to rounding.

Option 2 would move the Pu-238 MAR contained in 5,000 sf of PF-4 to one module, releasing 52 percent of the space of Pu-238 Programs and 91 percent of the MAR in those programs.[27] **Table**

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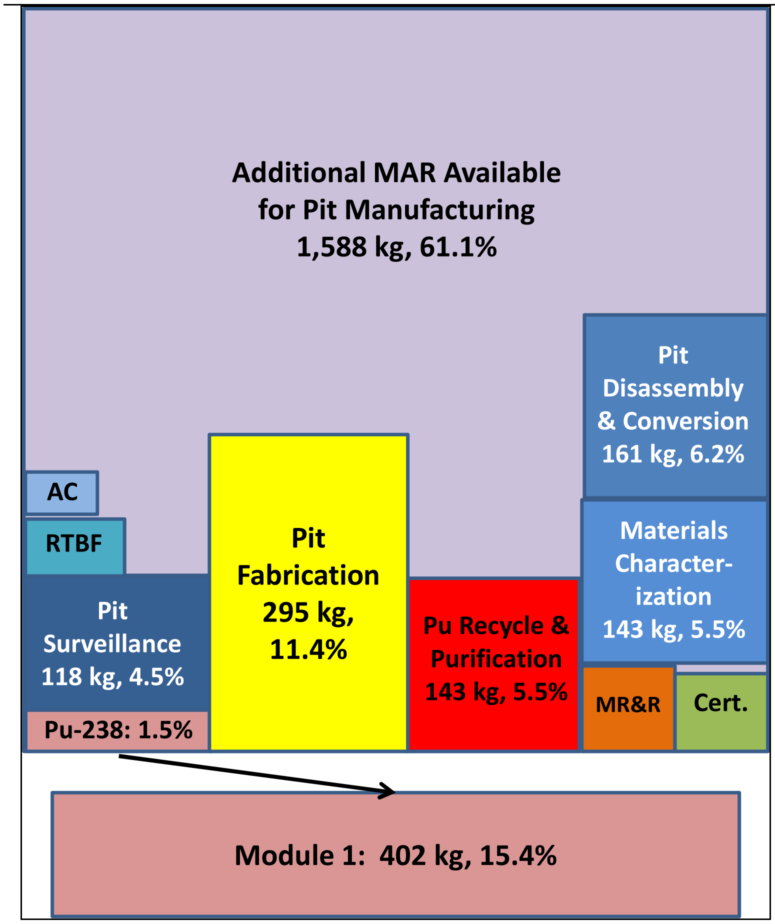
[27] Los Alamos National Laboratory provided the following data. As of February 27, 2013, Pu-238 programs accounted for 440.68 kg of MAR in PF-4 and 9,600 square feet (sf) of space. Based on an analysis of the MAR by room in the Pu-238 area, Los Alamos calculated that a 5,000-sf module could accommodate 401.55 kg of Pu-238 MAR. By this calculation, therefore, the module would hold 91 percent of the MAR. While the amount of MAR varies from day to day, the fundamental point shown by the data is that MAR is not spread evenly across a program area.

4 shows this option. (Tables 2 through 5 are drawn to the same scale.) MAR available for repurposing would also be allocated to pit fabrication. Under Option 2, pit fabrication would be allocated 72.4 percent of the 2,600 kg PE of MAR in PF-4. This option requires half as many modules and releases twice the MAR as Option 1.

Table 4. PF-4 MAR with One Module

Units in this graphic are kilograms of plutonium, not area
MAR allowance for PF-4 for this configuration is 2,600 kg of plutonium



	Program	MAR (kilo-grams)	Percent of PF-4 MAR allowance
	PF-4		
🟨	Pit Fabrication	295	11.4
🟪	AMAPM	1,588	61.1
🟩	Certification	34	1.3
🟦	Pit Surveillance	118	4.5
🟦	AC	14	0.5
🟦	MC	143	5.5
🟥	Pu-238 Programs	39	1.5
🟦	PDC	161	6.2
🟧	MR&R	38	1.5
🟦	RTBF	26	1.0
🟥	PRP	143	5.5
	Total	**2,600**	**100.0**
	Module 1		
🟥	Pu-238 Programs	402	15.4

Source: Data provided by Los Alamos National Laboratory; graphic by CRS.

Notes: MAR blocks represent, to scale, MAR allocations but not the physical location, form, or material type within PF-4. MAR blocks outside PF-4 (modules) are drawn to the same scale as those inside. Module 1 is for Pit Fabrication (2/3) and Plutonium Recycle and Recovery (1/3); Module 2 is for Plutonium Recycle and Recovery. MAR not used for other programs is assumed to be allocated to pit manufacture. Detail may not add to total due to rounding. The **Appendix** explains the programs in PF-4.

Abbreviations: AC, Analytical Chemistry; AMAPM, Additional MAR Available for Pit Manufacturing; MC, Materials Characterization; MR&R, Materials Recycle and Recovery; PDC, Pit Disassembly and Conversion; PRP, Plutonium Recycle and Purification; RTBF, Readiness in Technical Base and Facilities.

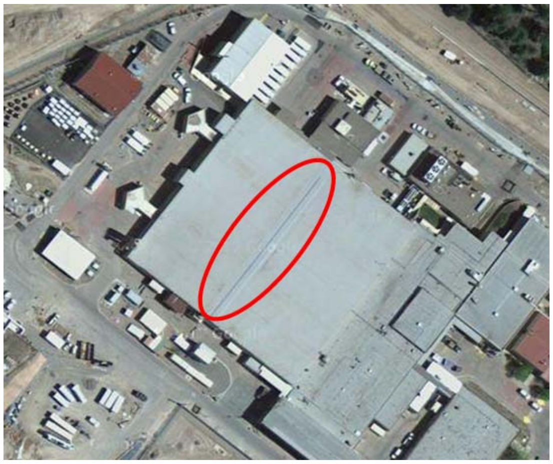
Option 3 (not shown) would move all Pu-238 work to INL or SRS. This would free up all the MAR, vs. 91 percent for Option 2 and, more importantly, as shown in **Figure 4**, would free up 9,600 sf of space, vs. 5,000 for Option 2.

Increasing MAR Margin Without Major Construction

As with space, it may be possible to increase MAR margin without major construction. One approach is to strengthen PF-4 seismically to reduce the risk of building collapse through such steps as wrapping supporting columns in carbon fiber bonded with epoxy to strengthen them,[28] anchoring the wall more strongly to the ceiling, installing braces that tie columns to beams, building shear walls, and installing a drag strut on the roof of PF-4 (see **Figure 5**).[29]

Figure 5. PF-4 Roof Showing Drag Strut

Drag strut is circled



Source: Google Maps.

Notes: See footnote 29 for a description of drag struts.

Other steps could reduce the risk that plutonium would escape even if PF-4 collapsed; plutonium escaping in an accident causes dose, and dose is the key factor in determining the amount of MAR permitted. Actual or possible steps include:

- Installing in production areas containers designed to remain intact in a building collapse; plutonium in these containers is not "at risk" and is thus not MAR;
- Removing tons of combustible material from PF-4;[30] and
- Anchoring gloveboxes more strongly to the floor to reduce the likelihood that an earthquake would knock them over, exposing plutonium to the air, in which case a fire could generate plutonium oxide particles and release them into the atmosphere.[31]

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[28] For a discussion of the use of this method in a large office building, see Mo Ehsani, "Fiber Reinforced Polymers: Seismic Retrofit of the McKinley Tower," *Structure Magazine,* Juny 2007, pp. 35-37.

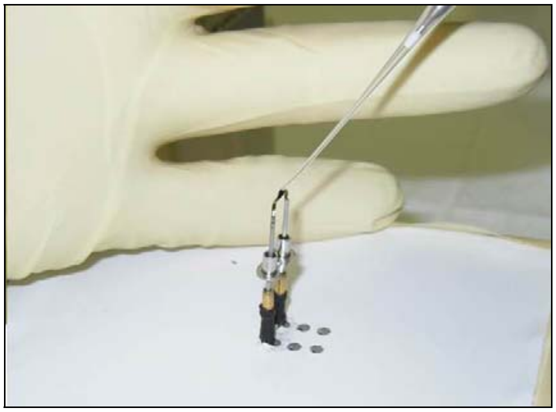
[29] Los Alamos National Laboratory provided some of this information, email and telephone communications, May 2014. Drag struts "gather the lateral earthquake loads from a large area of a building—a roof or floor diaphragm, for example—and deliver them to a structural element, such as a shear wall, that can resist the force." Thor Matteson, "Lateral-Force Collectors for Seismic and Wind-Resistant Framing," Purdue Practical Engineering, October 2003, p. 1, https://engineering.purdue.edu/~jliu/courses/CE479/extras/Lateral-Force%20Collectors.pdf. A shear wall is "a rigid vertical diaphragm capable of transferring lateral forces from exterior walls, floors, and roofs to the ground foundation in a direction parallel to their planes. Examples are the reinforced-concrete wall or vertical truss. Lateral forces caused by wind, earthquake, and uneven settlement loads, in addition to the weight of structure and occupants, create powerful twisting (torsional) forces. These forces can literally tear (shear) a building apart. Reinforcing a frame by attaching or placing a rigid wall inside it maintains the shape of the frame and prevents rotation at the joints. Shear walls are especially important in high-rise buildings subject to lateral wind and seismic forces." "Shear Wall," *Encyclopedia Britannica,* Academic Edition, http://www.britannica.com/EBchecked/topic/539298/shear-wall.

[30] Los Alamos removed about 20 tons of combustible material from PF-4 between 2010 and 2012. Letter from Donald Cook, Deputy Administrator for Defense Programs, National Nuclear Security Administration, to Peter Winokur, Chairman, Defense Nuclear Facilities Safety Board, January 30, 2012, Enclosure 2, p. 1, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Letters/2012/ltr_2012130_18446_0.pdf.

[31] This work is underway in PF-4. See Figure 16 in CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*, by Jonathan E. Medalia

Options for Analytical Chemistry

Figure 6. Preparing a Sample for an Analytical Chemistry Instrument



Source: Los Alamos National Laboratory.

Unlike pit manufacturing, AC involves little MAR because it uses tiny samples, such as a few milligrams of plutonium dissolved in a small amount of acid, as **Figure 6** shows. But AC involves much more space per unit MAR than does pit fabrication because each laboratory instrument is housed in a glovebox or hood that might occupy a dozen square feet of space. Many analyses must be performed for each individual pit, and the number of instruments and their housing increase in tandem with manufacturing capacity. Producing 80 ppy would require increasing AC capacity.

This requirement comes from two sources. First, at LANL, most pit-related AC is performed in the CMR building; as noted, NNSA plans to halt programmatic operations there "in approximately 2019." Given NNSA's plan to achieve a 30-ppy capacity by FY2026, work currently done in CMR would have to be performed elsewhere. Second, producing 80 ppy would require additional AC, as AC must be performed on multiple samples for each pit, and increasing manufacturing capacity would require more equipment, more space, and more MAR for AC.

Finding enough space and MAR for AC should be simpler than for pit manufacture because more options are readily available to meet requirements for AC than for pit manufacture. According to DOD, "At the height of the Cold War, the Department of Energy's Rocky Flats Plant produced between 1,000 and 2,000 pits per year."[32] The plutonium for each pit required AC. Because currently-anticipated rates do not approach that level, the nuclear weapons complex has a considerable amount of excess space and MAR suitable for AC. This capacity resides at several buildings in the complex, including Building 332 at Lawrence Livermore National Laboratory (LLNL), F/H Laboratory and Building 773-A at SRS, and the Radiological Laboratory-Utility-Office Building (RLUOB) at LANL. Each of these facilities would apparently have enough floor space and MAR allowance to conduct the AC needed to support manufacture of 80 ppy, PF-4 might perform some additional AC for higher-MAR work, such as sample preparation (which takes several-gram samples from larger pieces of plutonium) and certain analyses. **Figure 7** shows these options. In addition, R&D may reduce MAR requirements. For example, LANL is validating an AC system that may require a sample size of 1.5 mg of WGPu instead of 225 mg.[33]

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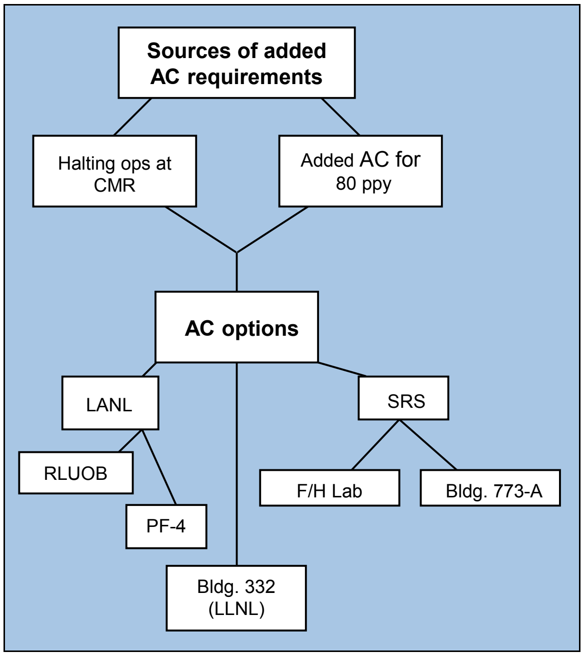
[32] U.S. Department of Defense. "Assessment of Nuclear Weapon Pit Production Requirements," January 2014, p. 2.

[33] Craig Leasure and Matthew Nuckols, *Los Alamos Initial Response for Maintaining Capabilities with Deferral of the CMRR Nuclear Facility Project,* Los Alamos National Laboratory, LA-CP-12-00470, April 16, 2012, p. 47. This document is Unclassified Controlled Nuclear Information, but this sentence is unclassified.

At issue are whether all AC should be done at LANL and, if not, how much AC should be done there and how much at another site. Not at issue is that LANL would need the *capability* to perform all AC tasks even if it did not have the *capacity* to perform AC for 80 ppy. The case for having a second site perform some of the AC needed for 80 ppy while maintaining the full suite of AC capabilities at LANL is:

Figure 7. Analytical Chemistry: Requirements and Options



Source: CRS.

- LANL is primarily a laboratory, and AC for 80 ppy would be on an industrial scale. LANL would gain little if any technical competence by conducting AC for 80 ppy vs., say, 40.
- It may be difficult to provide enough MAR and floor space at LANL for the AC for 80 ppy, especially with RLUOB's current MAR limit of 26 grams WGPu.
- LANL and a second site could cross-check the accuracy of each other's AC measurements and processes from time to time. LANL and LLNL have for decades, since before the end of nuclear testing, held that peer review is essential in developing or maintaining weapons and leads each lab to probe for flaws in the other lab's analyses, thus increasing confidence in the results. A similar argument could apply to peer review of AC.
- A second site could accommodate a surge in AC needs or provide a backup in case AC operations at LANL were suspended or disrupted.
- A second site would provide another source of technicians trained for plutonium AC.

Several factors argue for keeping all the AC at LANL.

- It might cost more to perform AC at two sites rather than one, though it is impossible to know without the data.
- A second site would necessitate shipping many plutonium samples per year from LANL to another site, which would increase the risk of an accident and could cause public concern.
- It might be beneficial to have all plutonium AC technicians at one site so they would have the same training and operate according to the same formal and informal procedures.
- Concentrating as much plutonium work as possible at LANL would strengthen its position as the nation's plutonium center.

While SRS and LLNL could both do this work, their facilities presumably have different capacities and would require different upgrades to support whatever level of AC was required. Data on the MAR and space requirements, and the cost of the LANL, LLNL, and SRS options, would be needed to provide a basis for decision.

A New NNSA Path Forward on Analytical Chemistry[34]

The option of having LLNL or SRS conduct a substantial fraction of the AC needed to support manufacture of 80 ppy must be evaluated in light of a revised path forward for AC that NNSA developed in June 2014. Based on an initial analysis by Los Alamos National Laboratory, NNSA determined that the combination of PF-4 and RLUOB with a higher plutonium limit, if properly equipped, could likely conduct all the AC needed to support manufacture of 80 ppy. NNSA further found that RLUOB would have sufficient space for the needed equipment. The planning for this approach will be conducted by personnel from NNSA headquarters (including the Office of Defense Programs, the Office of General Counsel, and staff specializing in construction and in National Environmental Policy Act issues), NNSA's Los Alamos Field Office, and Los Alamos National Laboratory over the summer and fall of 2014 to understand the costs and benefits of this approach.

A Radiological Facility like RLUOB is permitted to hold up to 38.6 grams of plutonium-239 equivalent (Pu-239E), or 26 grams of WGPu. Radiological Facilities do not require stringent safety or security measures because the dose to onsite or offsite personnel in the event of a worst-case accident would be very low. In contrast, a Hazard Category (HC) 3 facility can hold between 38.6 grams and 2,610 grams of Pu-239E, or about 26 to 1,760 grams of WGPu. NNSA considered several options for raising the MAR limit in RLUOB. One option was to retrofit the building by adding various safety upgrades to make it HC-3 at the highest level (1760 grams WGPu). That option would have been costly and time-consuming and was not necessary for conducting AC work required. Another option was to create a "Hazard Category 4," splitting off the lower part of the HC-3 range into a separate category, with the upper bound, say, 900 grams Pu-239E. That option, however, would have necessitated a revision of 10 CFR 830, Nuclear Safety Management, which would have required an extended period for rulemaking and would likely have impacted many other DOE facilities.

The various limits on plutonium are based on the dose to onsite workers and offsite personnel that a worst-case accident could be expected to cause, and the requirements for a building depend on dose. There are myriad other regulations, all of which come together in a document called a Documented Safety Analysis, or DSA, which is tailored to each building and specifies the amount of radioactive material the building can hold and still remain below the dose thresholds set by DOE Orders in the event of a worst-case accident. While each building in the Hazard Category system requires a DSA, a Radiological Facility, such as RLUOB, does not because the amount of radioactive material is so small. Therefore, to increase the amount of WGPu in RLUOB above 26 grams, NNSA would have to prepare a DSA to operate RLUOB as an HC-3 facility. NNSA calculated that RLUOB, with 400 grams WGPu, could likely be operated as HC-3 without significant facility modifications: because of modern building features in RLUOB, NNSA

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[34] Information in this section, excepting footnote 38, was provided by Don Cook, Deputy Administrator for Defense Programs, NNSA, and Michael Thompson, Assistant Deputy Administrator, Major Modernization Programs, NNSA, telephone conversation, July 7, 2014.

calculated that the dose from the increased material in a worst-case accident would still be below the dose thresholds set by DOE Orders.

Operating RLUOB as an HC-3 facility would not require congressional approval. Instead, congressional oversight would come through the normal reviews associated with the Chemistry and Metallurgy Research Replacement (CMRR) line item construction project. This line item remains open. It would fund actions that would accomplish the tasks proposed for CMRR-Nuclear Facility (NF), which NNSA stated in its FY2013 request were "plutonium chemistry, plutonium physics, and storage of special nuclear materials."[35] However, CMRR-NF was "deferr[ed] … for at least five years" in the FY2013 budget request on cost grounds.[36] NNSA plans to include funds for two subprojects in the CMRR line item construction project beginning with the FY2016 request. One is adding new AC equipment to RLUOB so it can perform AC to support 80 ppy; this would be "RLUOB Equipment Installation 2," or REI-2; the initial REI provided equipment for a much smaller amount of AC. AC equates to plutonium chemistry. The other involves PF-4: decontaminating some rooms, removing some old gloveboxes, and installing new materials characterization (MC)[37] equipment; this is "Plutonium Equipment Installation," or PEI. PEI would support MC, and relates to plutonium physics. A separate activity, not part of the CMRR project, is removing excess special nuclear materials from the storage vault in PF-4, work that has been underway for some years.[38]

As a result, these three elements would permit NNSA to perform all the tasks planned for CMRR-NF, the cost of which was projected in the FY2012 budget request to be between $3,710 million and $5,860 million.[39] While there are no cost estimates for NNSA's path forward, it would cost substantially less than CMRR-NF because it would avoid building a large plutonium facility.

NNSA requested FY2015 funds for the AC and MC subprojects as part of the Program Readiness component of Readiness in Technical Base and Facilities (RTBF), which in turn is a component of NNSA's Weapons Activities account.[40] While the House Appropriations Committee recommended including these funds as RTBF Construction, using the CMRR line item to fund these projects is consistent with the committee's recommendation:

> *04-D-125, Chemistry and Metallurgy Research (CMR) Replacement Project, LANL.*—The Committee recommends $35,700,000, instead of providing funds for these activities under

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[35] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2013 Congressional Budget Request,* Volume 1, National Nuclear Security Administration, DOE/CF-0071, February 2012, p. 185. Special nuclear materials are essentially uranium enriched in the isotope 235 and plutonium.

[36] Ibid.

[37] Materials characterization measures bulk properties of plutonium, such as tensile strength, magnetic susceptibility, grain structure, and surface characteristics, and uses samples on the order of a fraction of a gram to tens of grams. In contrast, analytical chemistry, which measures such chemical properties of plutonium as impurities and isotopic composition, typically uses samples on the order of milligrams.

[38] Much material can be removed from the vault. As of early 2012, approximately 30 percent of the PF-4 vault space was "occupied by material of use to programs," 66 percent was occupied by "materials of no current value to the programs," and 4 percent was "available space." Leasure and Nuckols, *Los Alamos Initial Response for Maintaining Capabilities with Deferral of the CMRR Nuclear Facility Project,* p. 77. This document is Unclassified Controlled Nuclear Information, but the preceding sentence is unclassified.

[39] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2012 Congressional Budget Request,* Volume 1, National Nuclear Security Administration, DOE/CF-0057, February 2011, p. 237.

[40] U.S. Department of Energy. Office of Chief Financial Officer. *FY 2015 Congressional Budget Request.* Volume 1, National Nuclear Security Administration. DOE/CF-0096, March 2014, p. 213.

> Program Readiness as in the budget request. This approach is consistent with the Committee's previous direction to the NNSA to carry out all CMR replacement activities in accordance with DOE Order 413.3B, rather than within operations funding where there is little transparency or accountability for delivering these activities on time and within budget. While the capacity and amount of process equipment needed may be evolving due to changing programmatic requirements for plutonium, the scope of the additional work being requested is consistent with the original mission need to provide analytic chemistry and material characterization space in a different facility than the legacy CMR building. Similarly, PF-4 reconfiguration activities are also appropriate to be conducted as part of the original CMR Replacement project so long as they are limited to re-equipping lab space for capabilities that were previously housed in the legacy CMR building. Construction of new modular facilities and installation of equipment within PF-4 to establish enhanced pit production capabilities are not sufficiently related to the original mission need of the existing project, and the Committee does not support the inclusion of these activities as subprojects within the existing CMR replacement project.[41]

REI-2 and PEI would also permit NNSA to exit the CMR building, a long-time goal of NNSA for several reasons:

- a fault runs underneath the building;
- CMR was built to the seismic standards of the late 1940s, so it is much more vulnerable to collapse in an earthquake than is RLUOB, placing its workers at heightened risk; and
- studies have found it to be "decrepit" and "structurally unsound," as noted under "Terminology."

NNSA points out that—comparing the quantity of plutonium, the age, and the structural integrity of the two buildings—having 9 kg of plutonium in CMR, as at present, poses a much greater risk than having 400 grams of plutonium in RLUOB.

If NNSA is able to implement its path forward, LANL could perform all the AC needed to support manufacture of up to 80 ppy. In that case, the key question for AC would be how much, if any, AC one or more sites other than LANL should perform.

Decisions Require Data

The foregoing discussion shows how much additional space and MAR various construction options would make available for pit manufacturing, and points out that various non-construction options would also increase space and MAR margins. LANL has provided data from which this report calculated how much MAR and space various options would make available. The data, however, cannot indicate which options, if any, would provide *enough* margin because data on space and MAR *requirements* are also needed to calculate margin. It might turn out that once seismic improvements are made, PF 4 would have enough space and MAR margin for 80 ppy, or that moving Pu-238 programs to a module might free up enough MAR but not enough space for 80 ppy, or that moving Pu-238 programs to another site would suffice. (Other factors may enter

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[41] U.S. Congress, House Committee on Appropriations, *Energy and Water Development Appropriations Bill, 2015*, report to accompany H.R. 4923, 113th Cong., 2nd sess., June 20, 2014, H.Rept. 113-486 (Washington: GPO, 2014), pp. 135-136.

into feasibility as well, such as the condition of a building.) But without data for space and MAR needed to manufacture 80 ppy, one cannot know which options are infeasible, which provide excess capacity and thus entail excess cost, and which are "just right."

Regarding AC, the discussion shows that there are multiple options to provide AC capacity, and highlights the issue of whether all AC should be done at LANL and, if not, how much AC should be done there and how much at another site. But without data on such matters as building condition and cost for any required upgrades and equipment, it is not possible to determine the relative merits of the options.

Figure 8 shows a notional decision sequence for downselecting pit manufacturing options. After defining options meriting consideration, the first question is, Which options are feasible? It would be simple to compare data on the required MAR and space, once they become available, against the amount of MAR and space released by each option to see which options provide a positive margin. Non-feasible options would not merit further consideration. The next step would be to estimate the cost of the feasible options and decide which are affordable. These data are needed to eliminate unaffordable options, which is important before planning begins because high cost has caused the demise of several nuclear weapons complex projects. Finally, having downselected to options that are feasible and affordable, one would compare those options against other possible criteria in order to make a final choice. Not shown in the figure is that MAR and space margins may change over time, as **Figure 1** shows; such changes may make currently-feasible options infeasible, and vice versa.

Figure 8. Notional Decision Sequence for Downselecting Pit Manufacturing Options

Options	A	B	C	D	E	F	G	H	I	J
Enough MAR?	YES	NO	YES	NO	YES	YES	NO	NO	YES	YES
Enough space?	NO	NO	YES	YES	YES	YES	NO	YES	YES	NO
Feasible set			C		F	E			I	
Cost ($B)			1.5		1.4	0.9			8.3	
Affordable?			YES		YES	YES			NO	
Feasible and affordable set			C		F	E				
Compare against other criteria			fair		excellent	poor				
Final selection					PROCEED					

Source: CRS.

Note: Options are notional, and do not represent any specific options.

Questions That Can Only Be Answered with Data

Congress would need data on MAR margin, space margin, and cost for various pit manufacturing options in order to best determine which options are feasible and affordable. The following questions highlight how these data could support decisionmaking.

Questions Requiring Data on MAR and Space

Questions such as the following can only be answered with data on how much MAR and space suffice for pit manufacturing and supporting AC for 80 ppy:

- Once certain seismic upgrades are completed, is there expected to be enough MAR margin for PF-4 to accommodate the added MAR needed to manufacture 80 ppy?
- As of 2012, 4,700 sf was available for immediate repurposing in PF-4. How much space is available now? Is that space, plus the 12,000 sf for pit fabrication, plus space for other pit-related tasks, enough to manufacture 80 ppy?
- If there is enough space and MAR margin in PF-4 for 80 ppy, is there a need to move any pit fabrication work (such as hemishell casting), Pu-238 work, or any other high-MAR work out of PF-4, whether to modules or to another site?
- If the MAR allowance in PF-4 is not sufficient to accommodate manufacture of 80 ppy, by how much would it have to be raised to do so? Could that be done, and if so what would the project entail?
- MAR is not evenly distributed across space. As noted, 91 percent of Pu-238 MAR was at one point concentrated in 5,000 sf of the 9,600 sf that Pu-238 Programs occupy in PF-4. (MAR usage within PF-4 changes from day to day; the MAR figure is for February 27, 2013.) Would moving this MAR into a 5,000-sf module make enough MAR and space available in PF-4 for manufacture of 80 ppy?
- Moving all Pu-238 work to INL or SRS would release a little more MAR but another 4,600 sf, as compared to a module. Would that release enough MAR and space in PF-4 to permit manufacture of 80 ppy?
- Would one module release enough MAR and space in PF-4 for pit manufacture? (This assumes that the immediately-repurposable space in PF-4 would also be used for pit manufacture.) If yes, would that be the case if pit casting were moved to the module, or if Pu-238 were moved to the module?
- Space in PF-4 is precious, as PF-4 is the only place in the United States that performs high-MAR, high-security work on plutonium and can manufacture pits. Unused space therefore represents opportunity for plutonium work forgone. Would moving 5,000 sf of Pu-238 work and 5,000 sf of pit casting equipment to two modules create unused space in PF-4? Would moving the entire Pu-238 line, 9,600 sf, to another site have the same result? Or would the released space be needed to accommodate added equipment needed to manufacture 80 ppy?

- At present, RLUOB is permitted to have 26 grams of WGPu MAR for AC, which is not nearly enough to perform the AC for 80 ppy. If this limit remains in place, how much more MAR and space would be needed for AC at LLNL or SRS?
- If the MAR limit for RLUOB is increased to 400 grams of WGPu for AC, how much more MAR and space, if any, would be needed for AC at LLNL or SRS?

Questions Requiring Data on Cost

- If the 26-gram limit is retained for RLUOB, would it be less costly to perform the remaining AC at LLNL or at SRS?
- What would it cost to enable RLUOB to hold 400 grams WGPu?
- If RLUOB could hold 400 grams of WGPu but that did not provide sufficient space for AC for 80 ppy, would it be less costly to perform the remaining AC at LLNL or at SRS?
- LANL is conducting projects to bolster the seismic robustness of PF-4, which may increase PF-4's MAR allowance from 1,800 to 2,600 kg PE (or more or less). If 2,600 kg PE is not enough MAR, could additional projects raise the MAR allowance enough to accommodate manufacture of 80 ppy, and what would they cost?
- LANL maintains that each successive module should cost less than the one before it, as lessons learned should drive down costs. On the other hand, it is possible that some lessons learned would lead to increased costs. What is the first module estimated to cost? The second?
- How sensitive is the cost of pit manufacturing to capacity, and what tradeoffs might a sensitivity analysis reveal? As a hypothetical example, if it cost an additional several billion dollars to move from 70 to 80 ppy, would it be worth spending the added money?
- Would it be less costly to move Pu-238 or hemishell casting to a module?
- Would it be less costly to move Pu-238 to INL, SRS, or a newly-built module?

Conclusion

In deciding how to proceed on pit manufacture, Congress would likely want to know if there is enough space margin and MAR margin for 80 ppy. Margin, the available resource (space or MAR) minus the required resource, must be greater than zero. Available space and MAR are known, as of certain dates, as this report shows. But space and MAR required for 80 ppy have not been rigorously calculated. Congress may choose to direct NNSA to provide these two numbers.

Once these numbers become available, Congress would face three decisions:

- For pit manufacturing, is there currently enough margin for space and MAR in PF-4? If not, what can be done to provide it?

- Once enough margin for space and margin for MAR are provided for pit manufacturing, what steps can be taken to maintain these margins over decades in the face of uncertainties?
- Space and MAR margins are not at issue for analytical chemistry because considerable excess space and MAR exist at other sites in the nuclear weapons complex. At issue: How much AC should be done at LANL, what is needed to make the space and MAR at LANL sufficient to support that amount of AC, and how much, if any, AC should be done at other sites?

Appendix. Plutonium Tasks in PF-4

This appendix explains the tasks included in the diagrams of PF-4 and, in so doing, explains what PF-4 does.

Analytical Chemistry (AC) analyzes plutonium samples taken from each pit at various stages in its manufacture. AC measures the isotopic composition of the plutonium and the amount of alloying materials and impurities a sample contains. AC typically uses samples on the order of milligrams.

Certification: Before a pit type can be accepted into the stockpile, it must be certified as acceptable for war reserve use. This involves validating weapons codes, among other things. Validation, in turn, draws on experimental data. PF-4 supports some of these experiments, such as by preparing samples for analytical chemistry and materials characterization and preparing test items for experiments at the Nevada National Security Site that do not produce a nuclear yield.

Materials Characterization (MC): MC measures bulk properties of plutonium, such as tensile strength, magnetic susceptibility, grain structure, and surface characteristics. Such properties must be determined in order to certify pit design, maintain process control, address process anomalies, and examine the condition of newly-manufactured pits and pits from the stockpile. MC typically uses samples on the order of a fraction of a gram to tens of grams.

Materials Recycle and Recovery (MR&R): MR&R examines containers of plutonium in PF-4 that are to be sent to WIPP for permanent disposition. If the containers have deteriorated, MR&R repackages the plutonium in new containers.

Pit Disassembly and Conversion: This area of PF-4 houses ARIES (Advanced Recovery and Integrated Extraction System), which converts excess pits to plutonium oxide (a powder) and places it in special containers for long-term storage.

Pit Fabrication involves, among other things, casting "hemishells" (half-pits) of plutonium, machining the cast hemishells to remove excess material, welding two together to form a pit, and inspecting the finished pit with x-ray imaging, physical measurements, etc., to ensure it meets specifications.

Pit Surveillance: Ever since the beginning of the nuclear weapons program, NNSA and its predecessor organizations have monitored the condition of nuclear weapons using a variety of techniques. Pits are monitored at Pantex Plant (TX) and PF-4. PF-4 monitoring techniques include taking physical measurements, checking for release of gases that may indicate deterioration of the pit, examining pits for corrosion, and taking pits apart to perform AC and MC on samples of the plutonium. While Pantex can perform some of these tasks, pits can be disassembled only at PF-4.

Plutonium-238 (Pu-238) Programs: Pu-238 is the heat source for radioisotope power systems (RPS) for space probes, and has military applications as well. It is manufactured by bombarding rods of neptunium-237 with neutrons in a nuclear reactor. It undergoes radioactive decay much more rapidly than does Pu-239, producing uranium and other impurities. As a result, old Pu-238 must be purified before it can be used. PF-4 receives Pu-238, removes the impurities through chemical processes, and makes plutonium oxide, which it presses into capsules. It mates some capsules with other equipment to make RPSs for military applications, and sends other capsules to Idaho National Laboratory, which does the same to make RPSs for space probes.

Plutonium Recycle and Purification (PR&P): This area recovers plutonium from scrap plutonium (such as from lathe turnings, pits scrapped for not meeting standards, or retired pits) for use in weapons and other programs. The scraps are dissolved in acid. Plutonium is then precipitated out of solution as plutonium oxalate, and is then roasted to produce plutonium oxide. A further process removes plutonium that remains in the acid. This area also recovers and purifies plutonium using high-temperature chemical processes.

Readiness in Technical Base and Facilities (RTBF): RTBF is NNSA's program for operating the nuclear weapons complex and maintaining its infrastructure. Within PF-4, RTBF space is used for functions that support multiple programs, such as shipping and receiving, waste management, and material control and accountability.

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Manufacturing Nuclear Weapon “Pits”: Paths toward 80 Pits Per Year

Presentation to
Nuclear Deterrence Summit

Jonathan Medalia
Congressional Research Service

February 19, 2015

Pit

- Fissile core of a nuclear weapon
- Uses plutonium
- Detonates the secondary stage
- No pit, no weapon

A Sisyphean History

- Cold War mfg capacity: 1,000-2,000 war reserve (WR) pits per year (ppy)
  - WR: pits accepted for use in the stockpile
  - Rocky Flats Plant halted ops in 1989
- Many facilities proposed since 1989
  - NMSF, Building 371, MPF, CNPC, Complex 2030, CMRR-NF
  - None succeeded
  - Two (NMSF, Bldg. 371) were built and torn down
  - No new plutonium processing facilities brought online since 1978 (PF-4)

Pit Manufacturing Capacity

- Zero since June 2013
  - PF-4 ops paused due to concerns over criticality safety and formality of ops
  - LANL working to restore PF-4 pit mfg to operating status
  - Equipment, processes, people for mfg are available
  - Also, no requirement to manufacture WR pits
  - Therefore, some quality assurance processes to certify pits as WR have been suspended

80 ppy: Now Required by Law

- DoD requirement
- Some argue for higher or lower numbers
- But P.L. 113-291, FY2015 National Defense Authorization Act:
  - In 2024, manufacture 10 WR pits
  - In 2025, manufacture 20 WR pits
  - In 2026, manufacture 30 WR pits
  - For 3 months in 2027, manufacture at rate of 80
    - May be delayed 2 years if DoD, DOE report justification

What’s Needed to Manufacture 80?

- Manufacturing tasks
  - Material prep, pit fabrication, material control and accountability, quality control, waste mgmt, etc.
  - All tasks entail Material At Risk (MAR) and space
    - MAR: “The amount of radioactive materials (in grams or curies of activity for each radionuclide) available to be acted on by a given physical stress.” (DOE)
    - Space: laboratory floor space suitable for ops

Margin

- $\text{Margin}_{\text{space}} = \text{Available}_{\text{space}} - \text{Required}_{\text{space}}$
- $\text{Margin}_{\text{MAR}} = \text{Available}_{\text{MAR}} - \text{Required}_{\text{MAR}}$
- These produce static, point-in-time numbers

Calculating Margin: Is There Enough?

- Critical question for Congress, NNSA, DoD
- “Enough” = margin > 0
- Need 4 numbers:
  - 1. MAR available for mfg
  - 2. MAR required for mfg
  - 3. Space available for mfg
  - 4. Space required for mfg
  - These numbers can change over time
- 1 and 3 are available (may need updating)
- 2 and 4 have not been calculated rigorously for 80 ppy, so cannot know how much is enough

Margin and Uncertainties

- Uncertainties may creep in over time, affecting availability and requirements for MAR and space
- Thus need margin to offset uncertainties
- Examples of uncertainties
  - Requiring more ppy increases demand for space, MAR
  - A new regulation reduces available MAR
  - Removing unneeded Pu from PF-4 increases available MAR
- More examples …

Uncertainties, over Decades, May Alter Space and MAR Required and Available for Pit Mfg

	Factors	Example I	Example 2	Example 3	Example 4
1	🟩 Factors increasing supply (availability) of MAR	Develop and install means to increase PF-4 seismic resilience	Clean out PF-4 vault, store more Pu needed for ongoing work in vault	Remove unneeded plutonium	New interpretation of a regulation permits increased MAR (as with RLUOB)
2	🟥 Factors reducing supply (availability) of MAR	A previously unknown seismic fault is discovered at TA-55	New interpretation of a regulation tightens restrictions	Cracks in concrete from earthquake reduce confidence in PF-4	Defense Nuclear Facilities Safety Board raises concern about an existing procedure
3	🟩 Factors increasing supply (availability) of space	More efficient use is made of PF-4 basement; some lab operations are moved there	Build modules	Clean out and repurpose rooms in PF-4	Add shielding around gloveboxes, permitting more in a room
4	🟥 Factors reducing supply (availability) of space	Add non-pit mission in PF-4	Pit manufacture uses more equipment than previously thought	A new regulation requires increasing space between gloveboxes to reduce dose	Contamination from an accident prevents use of a room in PF-4 for some time
5	🟥 Factors increasing demand (requirements) for MAR	Requirement changed to 125 ppy because of geopolitical developments	Faster process exposes more MAR	Partial collapse shuts CMR; its plutonium is moved to PF-4	Problem in a deployed weapon brings more pits to PF-4 for analysis
6	🟩 Factors reducing demand (requirements) for MAR	Requirement changed to 40 ppy because pit reuse proves more applicable than expected	Place more plutonium in highly robust containers	Develop lower-MAR manufacturing processes	Move Pu-238 mission out of PF-4
7	🟥 Factors increasing demand (requirements) for space	Requirement changed to 125 ppy because pit surveillance reveals unexpected pit problems	Workload for processing drums containing plutonium waste abruptly increases	A new manufacturing layout increases throughput but uses more space	Pit Disassembly and Conversion workload increases
8	🟩 Factors reducing demand (requirements) for space	Requirement changed to 40 ppy because plutonium is found to age more slowly than previously thought	Use 2 or 3 shifts per day	A new layout that minimizes space is designed	Some AC equipment is moved from PF-4 to RLUOB

Source: CRS. Green = factors increasing margin; red = factors reducing margin.

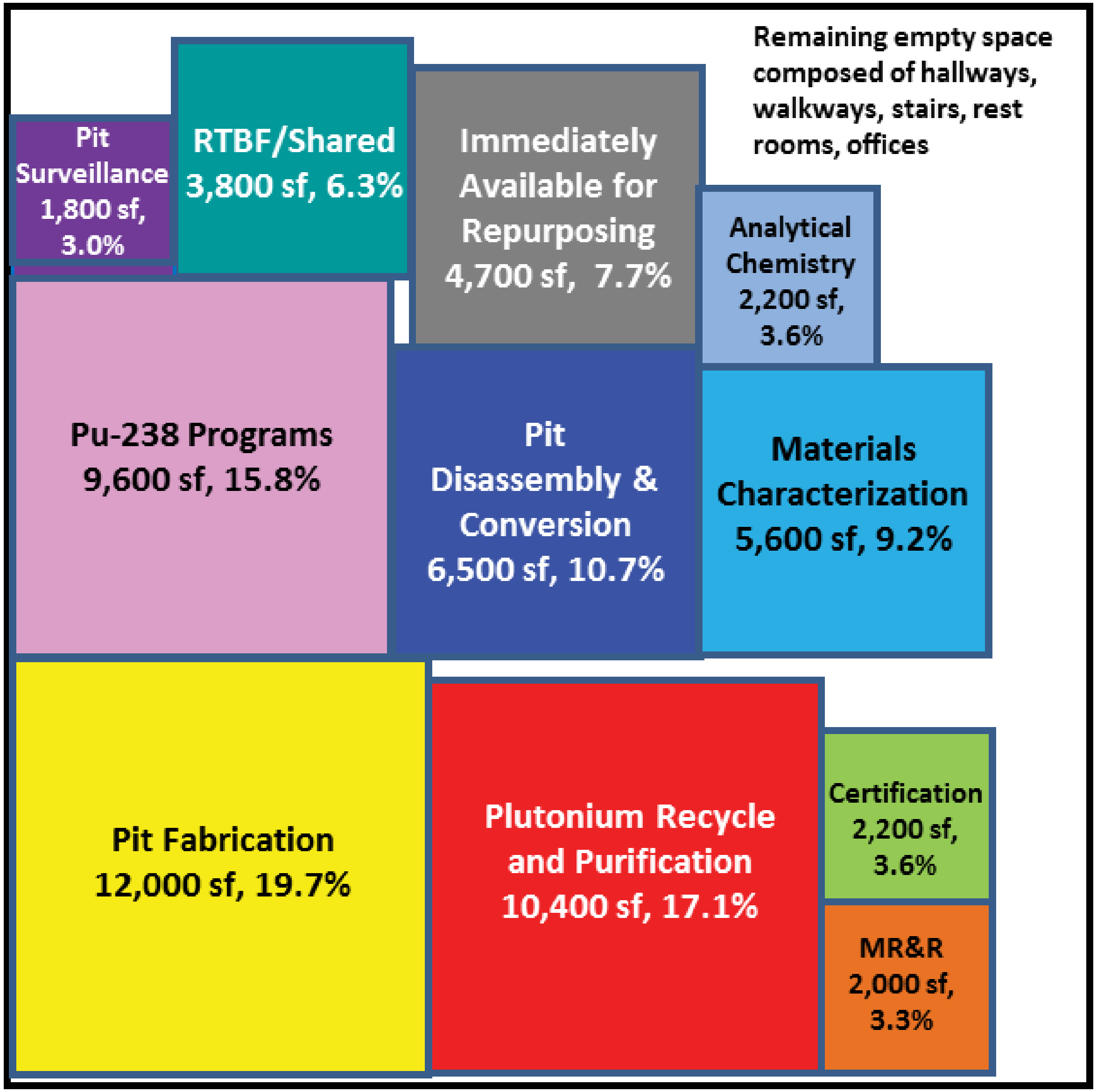
Key Decisions on Margin

- If there is not enough margin for space and MAR for 80 ppy, how can it be provided?
- Once there is enough margin, how can it be maintained over decades despite uncertainties?

Space: Providing and Maintaining Sufficient Margin

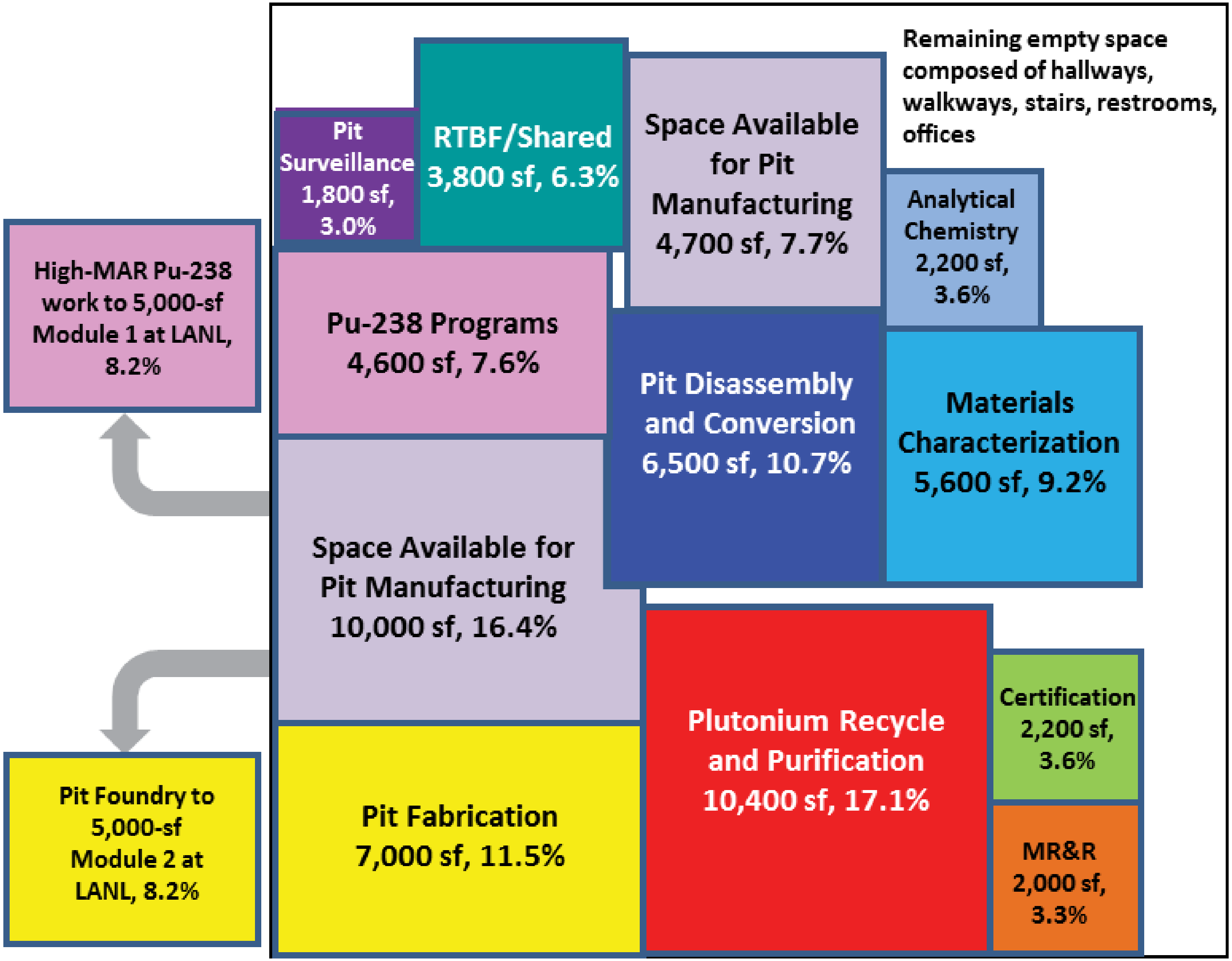
- Focus: PF-4 (Plutonium Facility 4)
  - Main Pu building at Los Alamos National Laboratory (LANL)
  - Only multi-program, multi-function, plutonium processing facility; only building that can currently make pits
- Various construction/non-construction options
  - Implement some promptly, hold others in reserve
  - Ability to maintain margin provides confidence in capacity
  - May assess margin annually

PF-4 Space Allocation as of Early 2012



Source: Los Alamos National Laboratory. The blocks in this diagram represent space allocations to scale, but do not show the physical location of each activity within PF-4.

Releasing Space in PF-4 with Two Modules



High-MAR Pu-238 work to 5,000-sf Module 1 at LANL, 8.2%

Pit Foundry to 5,000-sf Module 2 at LANL, 8.2%

Pit Surveillance 1,800 sf, 3.0%

RTBF/Shared 3,800 sf, 6.3%

Space Available for Pit Manufacturing 4,700 sf, 7.7%

Remaining empty space composed of hallways, walkways, stairs, restrooms, offices

Analytical Chemistry 2,200 sf, 3.6%

Pu-238 Programs 4,600 sf, 7.6%

Pit Disassembly and Conversion 6,500 sf, 10.7%

Materials Characterization 5,600 sf, 9.2%

Space Available for Pit Manufacturing 10,000 sf, 16.4%

Plutonium Recycle and Purification 10,400 sf, 17.1%

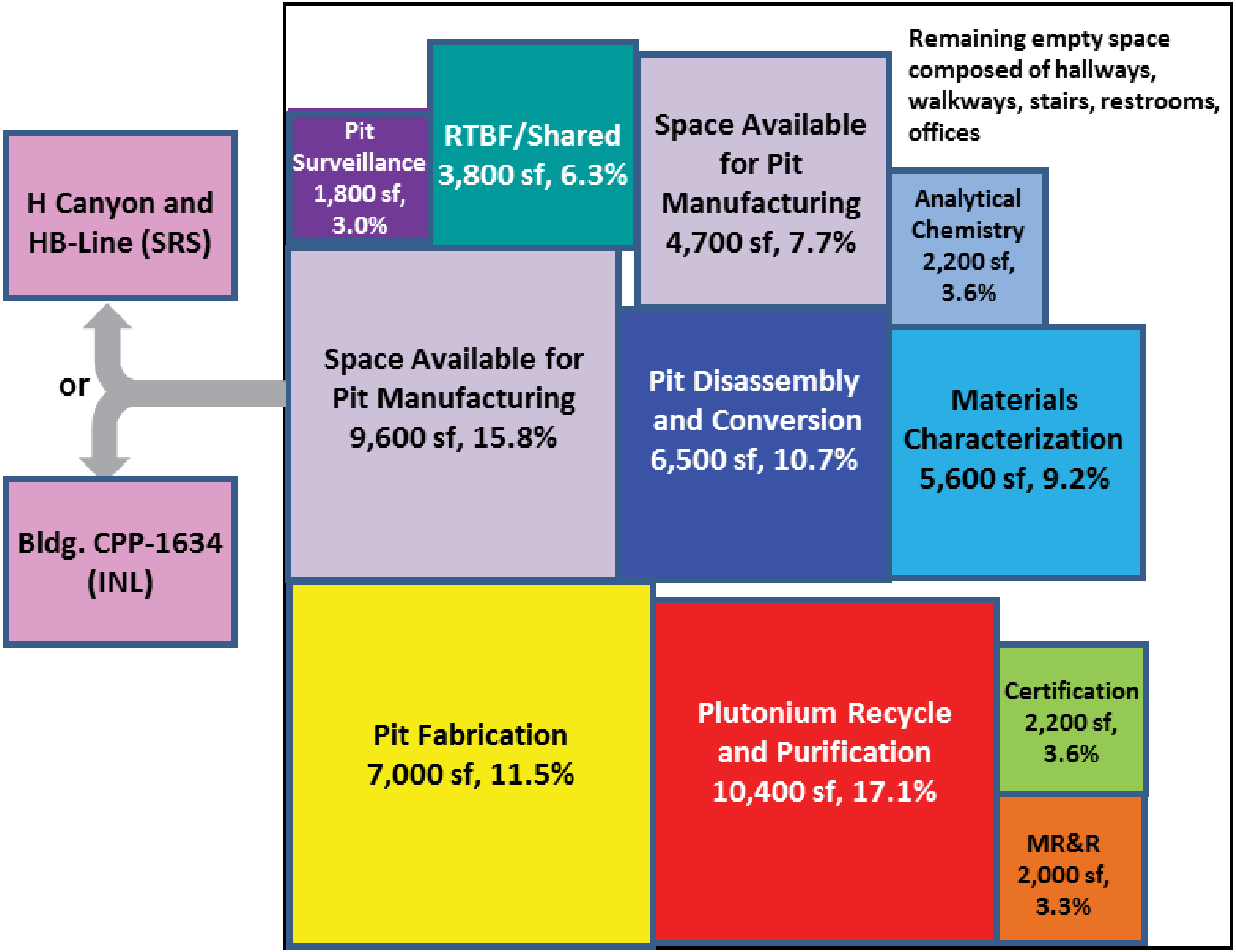
Certification 2,200 sf, 3.6%

Pit Fabrication 7,000 sf, 11.5%

MR&R 2,000 sf, 3.3%

Source: Base graphic, Los Alamos National Laboratory, modifications by CRS. The blocks in this diagram represent space allocations to scale, but do not show the physical location of each activity within PF-4.

Releasing Space in PF-4 by Moving Pu-238 Offsite



Source: Base graphic, Los Alamos National Laboratory, modifications by CRS. The blocks in this diagram represent space allocations to scale, but do not show the physical location of each activity within PF-4.

Increasing Space Margin in PF-4 for Mfg without Major Construction (Examples)

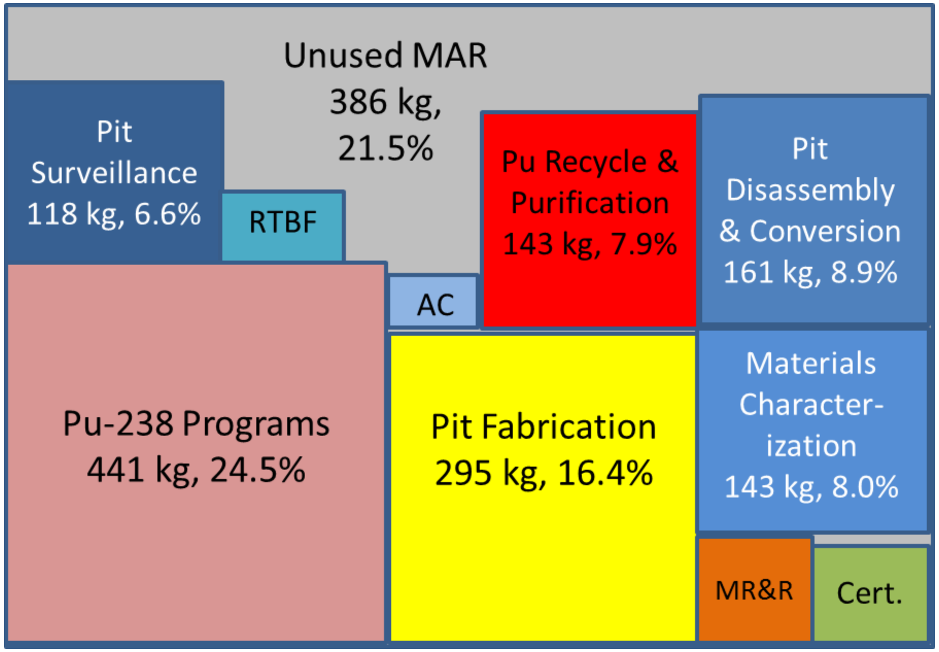
- Use additive mfg. to fabricate segmented crucibles for electrorefining Pu
- Repurpose unused or lower-priority space
  - E.g., remove unused gloveboxes
- Make better use of basement
- Use 2 or 3 shifts per day
- Use CaCl, not NaCl-KCl, in electrorefining Pu

MAR: Providing and Maintaining Sufficient Margin

- Focus: PF-4
- Various construction/non-construction options

PF-4 MAR Usage by Program on 2/27/2013

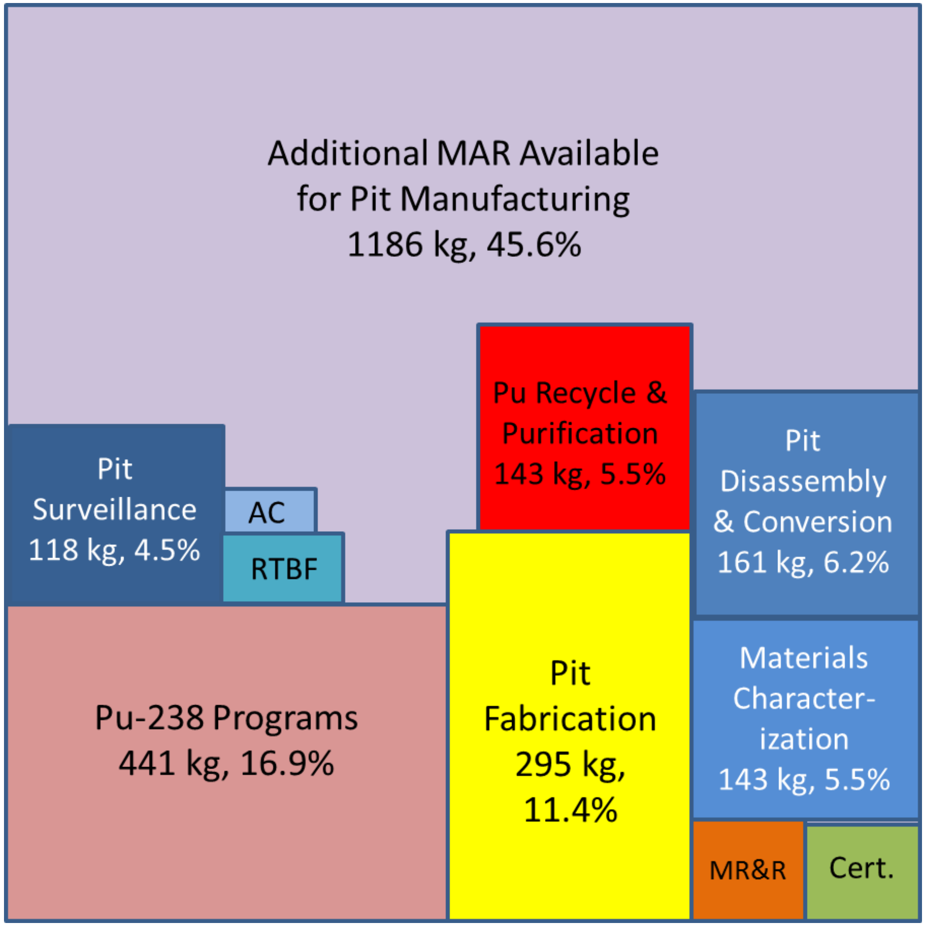
Units in this graphic are kilograms of plutonium, not area
MAR allowance for this configuration is 1,800 kg of plutonium



Source: Los Alamos National Laboratory. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4. MAR allowance for this and the next three slides is for the main laboratory floor of PF-4.

PF-4 MAR with Seismic Upgrades

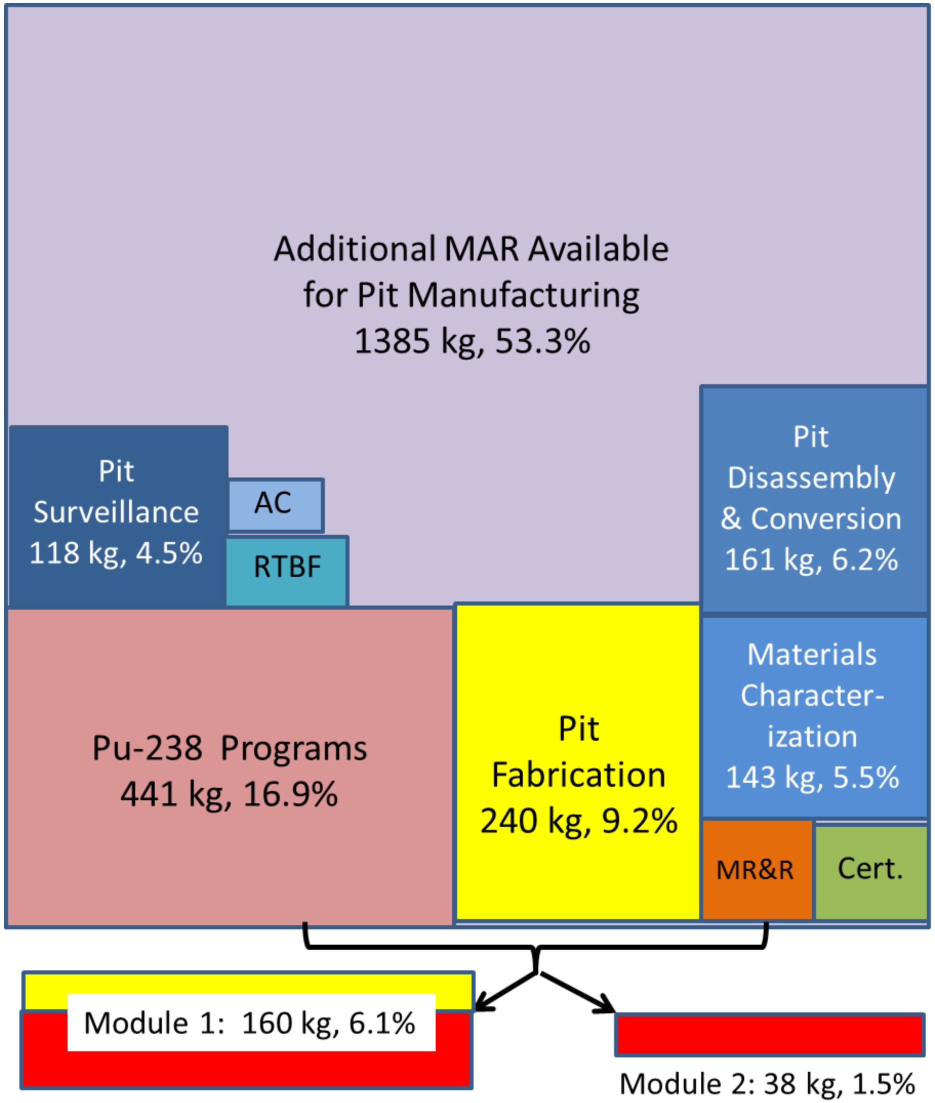
Units in this graphic are kilograms of plutonium, not area
MAR allowance for this configuration is 2,600 kg of plutonium



Source: Data provided by Los Alamos National Laboratory, graphic by CRS. MAR available for pit manufacturing in this and the next two slides has increased because seismic upgrades are assumed to permit a substantial increase (here, 44%) in PF-4 MAR. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4.

PF-4 MAR with Two Modules

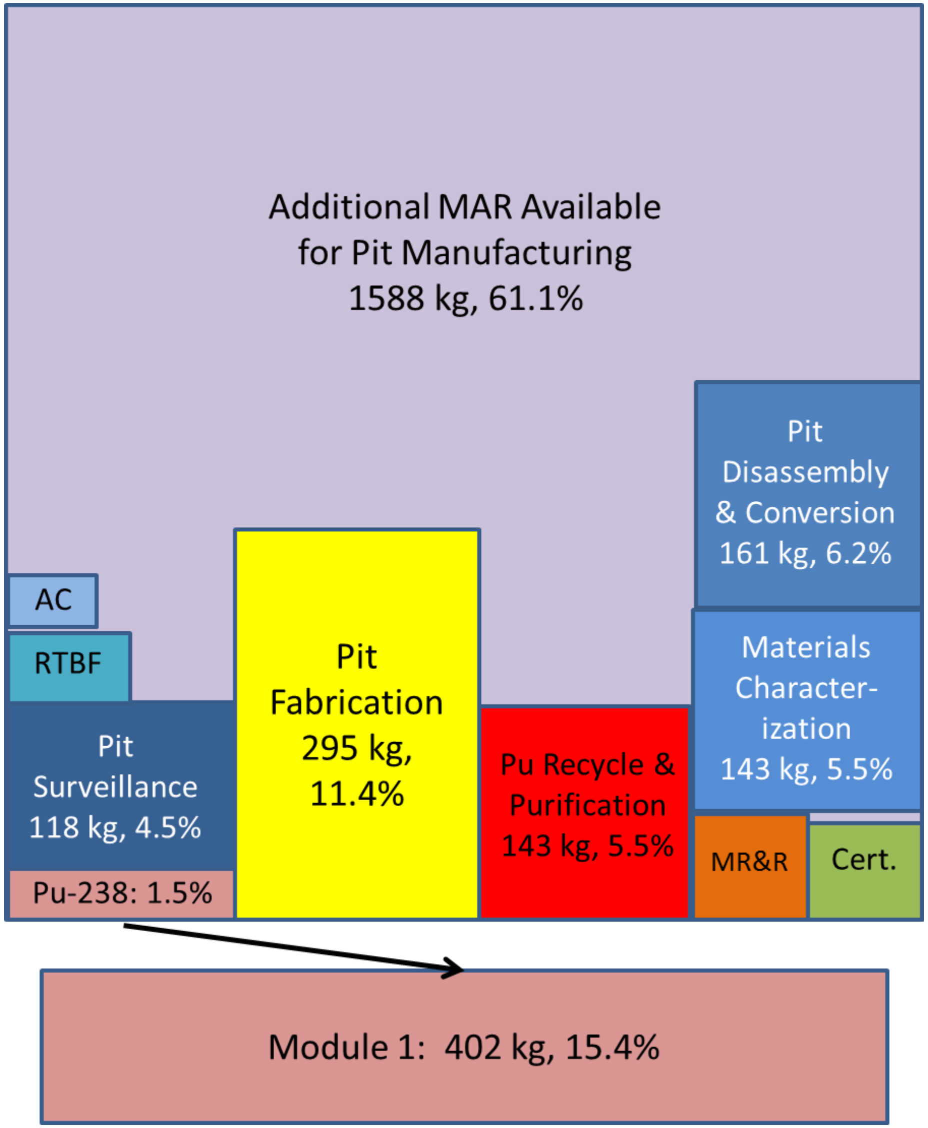
Units in this graphic are kilograms of plutonium, not area
MAR allowance for PF-4 for this configuration is 2,600 kg of plutonium



Source: Data provided by Los Alamos National Laboratory, graphic by CRS. Module 1, molten Pu operations; Module 2, aqueous (acid) processing of Pu. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4.

PF-4 MAR with One Module

Units in this graphic are kilograms of plutonium, not area
MAR allowance for PF-4 for this configuration is 2,600 kg of plutonium



Source: Data provided by Los Alamos National Laboratory, by CRS. The blocks in this diagram represent MAR allocations to scale, but do not show the physical location of each activity within PF-4.

Increasing MAR Margin in PF-4 without Major Construction (Examples)

Photo: Google Maps. Photo shows PF-4 roof with drag strut circled.

- Strengthen PF-4 seismically
  - Wrap columns; shear walls; reinforce ceiling; drag strut
  - These reduce risk of PF-4 collapse in design basis earthquake
- Reduce risk that PF-4 collapse releases Pu
  - Install rugged containers in production areas
  - Anchor gloveboxes more strongly to floor
  - Remove tons of combustible material from PF-4

Increase MAR by Avoiding Hyper-conservative Calculations of Dose

- MAR permitted for each building depends on calculation of dose
- Ten-factor equation links MAR to dose

Dose as Function of MAR for PF-4 Using Conservative and Hyperconservative Assumptions

Factor	Conservative	Hyperconservative
MAR, g Pu-239 equiv (Pu-239E)	2.60E+06	2.60E+06
Damage Ratio, DR	0.1	1
Airborne Release Fraction, ARF	0.0003	0.002
Respirable Fraction, RF	0.3	0.5
Leak-Path Factor	0.1	1
"Chi over Q," X/Q (s/m^3)	1.00E-06	8.77E-05
Breathing Rate, BR (m^3/s)	0.00033	0.00033
Specific Activity, SA (Ci/g) for Pu-239E	0.0622	0.0622
Dose Conversion Factor, DCF (rem/Ci)	5.92E+07	5.92E+07
Dose (rem)	.00474	166
Dose guideline (rem) per DOE regs	5-25	5-25

Factors are based on DOE rules except Chi over Q, which is specific to TA-55 (main plutonium area at LANL). Chi over Q includes such factors as distance, wind speed, wind direction, and deposition rate. ARF is specific to material form and accident scenario.

Increase MAR by Avoiding Hyper-conservative Calculations of Dose

- “When several input parameters are taken at their bounding values, the obtained result dwarfs the derived 95th percentile of the output by orders of magnitude.” (K. Jamali)
- Using conservative instead of hyperconservative assumptions reduces dose by 35,000x

Wrapup

- Many paths toward 80 ppy
- Can’t know which ones provide enough margin without data on MAR and space requirements
  - No changes may be needed, or
  - Non-construction options may suffice, or
  - Minor construction may suffice, or
  - Major construction may be required
    - Can’t tell if 0, 1, 2, or 3 modules would be necessary
    - Can’t tell if 0, 1, 2, or 3 modules would be sufficient

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Nuclear Weapon "Pit" Production: Options to Help Meet a Congressional Requirement

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CRS REPORT
Prepared for Members and
Committees of Congress

Summary

A pit is the plutonium core of a thermonuclear weapon. Imploding it with conventional explosives provides the energy to detonate the rest of the weapon. The Rocky Flats Plant made up to 2,000 pits per year (ppy) through 1989; since then, the United States has made 29 pits for the stockpile. Yet the FY2015 National Defense Authorization Act requires the National Nuclear Security Administration (NNSA), which manages the nuclear weapons program, to produce at a rate of 80 ppy for 90 days in 2027. How can that requirement be met?

Pits are to be made at Los Alamos National Laboratory’s main plutonium facility, PF-4. To manufacture pits, a facility must have enough laboratory floor space and a high enough limit for Material At Risk (MAR), the amount of radioactive material a worst-case accident could release. Producing 80 ppy requires enough “margin,” the space or MAR available to produce pits minus space or MAR required for that production rate. While space and MAR available have been calculated, amounts required to produce 80 ppy have never been calculated rigorously, leaving space and MAR needs undefined. Further, the report cannot address whether certain options could meet the 2027 date because time to implement them cannot be determined. Accordingly, this report presents 16 options that seek to increase the feasibility of producing 80 ppy by 2027, including:

- The radiation dose an individual would receive from a worst-case accident determines MAR permitted in PF-4. A ten-factor equation calculates dose as a function of MAR. NNSA uses worst-case values in this equation, yet median values may provide sufficient conservatism. Median values reduce calculated dose by orders of magnitude, permitting a large increase in PF-4 MAR. Yet merely doubling permitted MAR might suffice for producing 80 ppy. Providing this increase through construction at PF-4 could be costly and take years.
- In determining MAR for PF-4, the closest offsite individual is at a nearby trailer park. Relocating it would place the next closest individual farther away. The added distance would reduce dose, permitting increased MAR in PF-4.
- Using a different meteorological model and different assumptions would greatly reduce the currently calculated dose, perhaps permitting doubling PF-4 MAR.
- Plutonium decays radioactively, creating elements that various processes remove to purify plutonium. One process generates byproducts; plutonium is recovered from them with processes that take space and MAR. Since the United States has tons of plutonium surplus to defense needs, byproducts could be dispositioned as waste.
- Pits use weapons-grade plutonium (WGPu). U.S. WGPu is about 50 years old. About nine-tenths of plutonium-241, a WGPu isotope, decays to americium-241 in that time. Since plutonium-241 is the source of americium-241 in WGPu, removing the current americium-241 would prevent WGPu from ever reaching its americium-241 limit, permitting reduction in equipment for that process and reducing worker radiation exposure.
- A plutonium isotope used in space probes, plutonium-238, is extremely radioactive. It accounts for a small quantity of PF-4 plutonium but a quarter of PF-4’s MAR. Building a “module” near PF-4 for plutonium-238 work would free MAR and space in PF-4, so one module might suffice instead of two or three.

- To reduce risk of collapse, loss of life, and radiation release from an earthquake, NNSA increased the seismic resilience of PF-4. More steps are planned; more could be taken.

Achieving the congressionally mandated capacity will probably require choosing among options to create a package. MAR margin could be increased by relocating a trailer park, using a new meteorological model, installing rugged containers in the PF-4 production line, increasing PF-4's seismic resilience, and using less conservative assumptions in the MAR-to-dose equation. Similar choices exist for other options. At issue for Congress: What are the risks, costs, and benefits of the options? What is the optimum combination of options?

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Introduction

This is the third in a series of CRS reports on pit manufacturing.[1] A "pit" is the core of the primary stage of a thermonuclear weapon. Its key ingredient is weapons-grade plutonium (WGPu), which is composed mainly of the fissile isotope plutonium-239 (Pu-239) along with small quantities of other plutonium isotopes. Detonating the pit provides the energy to detonate a weapon's secondary stage.

During the Cold War, the Rocky Flats Plant (CO) made up to 2,000 "war reserve" pits per year (ppy). (A war reserve pit is one that has been accepted for use in the nuclear stockpile, as distinct from developmental or production prove-in pits.) Production at Rocky Flats halted in 1989. Since then, the United States has made 29 war reserve pits total for replacement in W88 submarine-launched ballistic missile warheads between 2007 and 2011.[2] Yet as discussed in "Install Equipment with a Single-Shift Capacity of 50 ppy," the Department of Defense (DOD) stated it needed the National Nuclear Security Administration (NNSA, the separately organized agency within the Department of Energy (DOE) in charge of maintaining the U.S. nuclear stockpile) to have the capacity to produce 50 to 80 ppy. This capacity, it is argued, would support nuclear weapon life extension programs, permit replacement of pits found to be defective, and address geopolitical developments.[3] Pits are to be made at Los Alamos National Laboratory (LANL, NM) in the PF-4 (Plutonium Facility 4) building, potentially in proposed smaller structures called modules that would be connected to PF-4 by tunnels, or in both.

In an effort to increase pit production capacity, Congress focused on inputs, such as requiring a plutonium processing building to be constructed by a certain date at a certain cost. However, in Section 3112 of P.L. 113-291, the Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, Congress changed tack and focused on output. It directed NNSA to ramp up pit production and demonstrate the capacity to produce at a rate of 80 ppy for at least a 90-day period in 2027. (The legislation permits extending this deadline by two years under certain conditions.) Accordingly, while some argue that the capacity should be larger and others hold that it should be smaller, this report takes as its focus how to move toward 80 ppy, not whether it is the right number.

Production at that rate requires enough "Material At Risk" (MAR) and space. DOE defines MAR as "the amount of radioactive materials … available to be acted on by a given physical stress."[4] It is material that could be released by a disaster, such as an earthquake that collapses a building followed by a fire. It is measured in units of plutonium-239 equivalent to convert all types of radioactive material to a common unit. Space is laboratory floor space, in square feet, available for plutonium operations. To measure "enough," this report uses the concept of margin, which is

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[1] The first two reports are CRS Report R43685, *Manufacturing Nuclear Weapon "Pits": A Decisionmaking Approach for Congress*, and CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*, both by Jonathan E. Medalia

[2] Marisa Sandoval, "Pit Perfect," *National Security Science,* a publication of Los Alamos National Laboratory, issue 3, 2011, http://www.lanl.gov/science/NSS/issues/NSS-Issue3-2011.pdf.

[3] For a discussion of this debate, see CRS Report R43406, *U.S. Nuclear Weapon "Pit" Production Options for Congress*, section titled "Pit Production Capacity: How Much Is Needed?"

[4] U.S. Department of Energy. DOE Handbook: Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities, Vol. I, Analysis of Experimental Data, DOE-HDBK-3010-94, December 1994, p. xix.

space available for pit production and supporting tasks minus space required for them to be able to produce at a specified rate, and MAR available for pit production and supporting tasks minus MAR required for them to do so. Space margin and MAR margin are separate; both must be greater than zero to accommodate pit production at the specified rate.

PF-4 has 60,000 square feet (sf) of laboratory space on its main floor. It supports many plutonium missions. Some involve pit production, such as pit fabrication (casting pits from molten plutonium) and purifying plutonium for use in pits; others include preparing plutonium-238 (Pu-238) for use as a power source for space probes, disassembly of pits and conversion of their plutonium to plutonium oxide, and surveillance of pits to check their condition. PF-4 has a ceiling on permitted MAR; as of February 2013, that ceiling was 1,800 kilograms Pu-239 equivalent. To provide perspective, in 2012 pit fabrication and plutonium purification accounted for 12,000 sf and 10,400 sf of PF-4's laboratory space, respectively; as of February 2013, they accounted for 295 kg and 143 kg Pu-239 equivalent of PF-4's MAR ceiling, respectively. A CRS report provides a detailed breakout of PF-4's space and MAR usage.┐

MAR and space also figure in a function that supports pit production, analytical chemistry (AC). AC analyzes very small samples of plutonium to determine the content of impurities, alloying material, and different isotopes of plutonium. AC techniques include mass spectrometry, x-ray fluorescence, radiochemistry, and material assay. The Radiological Laboratory-Utility-Office Building (RLUOB), which was completed in 2010 and is near PF-4, is to house most AC; PF-4 is to perform some higher-MAR AC and AC support work involving larger samples, such as material preparation. RLUOB's MAR ceiling is 38.6 g Pu-239 equivalent, though NNSA is evaluating a proposal to increase that to 400 g. AC equipment requires substantial laboratory floor space, and RLUOB has 19,500 square feet of space ideally configured for AC.

This report presents options that may increase margin, many of which NNSA and its laboratories are considering. However, while figures for space and MAR available for pit production exist, though they may need updating, *figures for space and MAR required to produce 80 ppy do not exist because they have never been calculated rigorously.* Accordingly, this report cannot find that one or more options would provide *enough* margin for producing 80 ppy or supporting AC. Instead, it presents a progression of options to move toward that goal: options not involving modifications to pit production processes; options involving modification to those processes but not structural modifications to PF-4; and options involving structural modifications to PF-4. While the options seek to increase the feasibility of producing 80 ppy by 2027, the report cannot address whether they could meet that date because time to implement them cannot be determined. Potential hurdles render schedules unpredictable. Construction may encounter delays. Moving equipment in PF-4, making structural changes, or changing plutonium processes must follow detailed procedures supported by extensive analysis. Organizations within DOE, oversight agencies, communities, nongovernmental organizations, and others may contest proposed changes to regulations or to assumptions used in calculations. Implementing such changes may be time-consuming; lawsuits may add delay. Efforts to develop new technologies may fail.

This report considers 16 options. A combination of these and other options may be needed to meet the congressional requirement. While any combination can only be selected if it provides enough MAR margin and enough space margin, other factors will also enter into a choice among options by Congress and NNSA. These include:

- reducing cost;
- accelerating schedule (i.e., making capacity available sooner);

- increasing throughput, the rate at which pits are made or processes completed;
- improving worker safety, which includes reducing the risk of injury from building collapse, fire, industrial accidents, and radiation exposure;
- reducing the risk to the public from radiation exposure if PF-4 were to release a large quantity of plutonium as a result of an earthquake or major accident; and
- reducing radioactive waste.

Each option contributes to increasing the feasibility of producing at a rate of 80 ppy by 2027. **Table 1** summarizes the contributions of each option to that requirement; each section of the report begins with a few words highlighting the most important contributions of that option.

Table 1. Contributions of 16 Options to Increasing Feasibility of Producing at a Rate of 80 Pits Per Year by 2027

Report Section	Increase space margin	Increase MAR margin	Reduce cost	Accelerate schedule	Increase throughput	Improve worker safety	Reduce risk to public	Reduce waste
50 ppy with 1 shift, 80 with 2	x		x	x				
Royal Crest		x	x	x			x	
Pu dispersion		x	x	x				
Remove contaminated eqpt	x				x	x		
Conservative assumptions		x	x	x				
Additive mfg for tooling			x	x				
Fabricate crucibles			x		x	x		x
Containers		x				x	x	
Process samples	x	x	x		x			x
Discard byproducts	x		x		x			x
Calcium chloride	x		x		x			x
Remove americium	x	x	x			x		
Accept more uranium	x		x		x			
Near net shape casting		x	x					x
PF-4 seismic resilience		x				x	x	
Pu-238 module	x	x					x	

Source: CRS.

Options Not Involving Process Modifications

Install Equipment with a Single-Shift Capacity of 50 ppy

This option holds the potential to reduce space requirements and cost, and to accelerate schedule.

DOD has stated a need for NNSA to have a capacity to manufacture 50 to 80 ppy. As John Harvey, then Principal Deputy Assistant Secretary of Defense for Nuclear, Chemical, and Biological Defense Programs, said in 2013,

> We established that requirement back in 2008 for a capability to produce in the range of 50 to 80 per year. That evolved from a decision to basically not take the path that we originally were taking with the Modern Pit Facility, but to go and be able to exploit the existing infrastructure at Los Alamos to meet our pit operational requirements. The capability at Los Alamos was assessed to be somewhere in the range of 50 to 80 per year that they could get with the modernization program they anticipated. The Nuclear Weapons Council looked at that number. It's a capacity-based number, and said it's probably good enough. We'll have to accept some risk, but it's probably good enough.[5]

As it happens, Los Alamos "estimates that a second shift would increase pit-manufacturing capacity by 60% so that establishing a 50-ppy capacity could supply 80 ppy using a second shift."[6] This range leaves uncertain whether there will be a need for 80 ppy, or whether 50 ppy would suffice. Adding to this uncertainty are NNSA's decision to defer to FY2030 the projected delivery of the first production unit of the first interoperable warhead (IW-1),[7] which might be the first to use a newly manufactured pit since 2011; the possibility that certain retired pits might prove suitable for reuse, reducing the number of newly manufactured pits needed; and the possibility that pit lifetime could turn out to be longer than currently expected. (Estimates of pit lifetime have increased. In 2003, pit life was thought to be 45 to 60 years.[8] A 2007 study placed the intrinsic life for plutonium in most pit types in the stockpile at over 100 years.[9] A 2012 study by Lawrence Livermore National Laboratory placed the figure at 150 years; Los Alamos raised uncertainty about that claim.[10])

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[5] Reserve Officers Association, Air Force Association and National Defense Industrial Association Capitol Hill Breakfast Forum with Linton Brooks, Senior Adviser at the Center for Strategic and International Studies; and John Harvey, Principal Deputy Assistant Secretary of Defense for Nuclear, Chemical and Biological Defense Programs, on "The Nuclear Infrastructure Challenge And Deterrence Implications," June 13, 2013, http://secure.afa.org/HBS/transcripts/2013/June%2013%20-%20Brooks.pdf. The Modern Pit Facility was to be a pit factory. NNSA approved a mission need for the facility in FY2002, with a capacity between 125 and 450 ppy; Congress eliminated funds for it in the FY2006 budget cycle.

[6] Information provided by Los Alamos National Laboratory, email, April 1, 2015.

[7] U.S. Department of Energy. Office of Chief Financial Officer, *FY 2015 Congressional Budget Request*, Volume 1, National Nuclear Security Administration, DOE/CF-0107, Washington, DC, February 2015, p. 94, http://www.energy.gov/sites/prod/files/2015/02/f19/FY2016BudgetVolume1%20_1.pdf.

[8] U.S. Department of Energy. National Nuclear Security Administration, Draft Supplemental Programmatic Environmental Impact Statement on Stockpile Stewardship and Management for a Modern Pit Facility, Summary volume, DOE/EIS-236-S2, Washington, DC, May 2003, pp. S-12, http://energy.gov/sites/prod/files/EIS-0236-S2-DEIS-Summary-2003_1.pdf.

[9] R.J. Hemley et al., Pit Lifetime, The MITRE Corporation, JASON Program Office, JSR-06-335, McLean, VA, January 11, 2007, p. 19, http://www.fas.org/irp/agency/dod/jason/pit.pdf.

[10] See Arnie Heller, "Plutonium at 150 Years: Going Strong and Aging Gracefully," *Science & Technology Review,* (continued...)

Compared to equipment to manufacture 80 ppy with a single shift, installing equipment to manufacture 50 ppy with a single shift would reduce cost and space because fewer pieces of equipment would be needed. Space reduction is of particular value because if this and other space-saving techniques could enable pit production to be done in PF-4, it may be possible to avoid the need for one or more modules for that purpose, potentially avoiding several billion dollars of added cost.

There are several disadvantages to building capacity for 50 ppy as a means to reach production of 80 ppy. A higher operating tempo would place more strain on the equipment while allowing less time in which to maintain and repair it, though this disadvantage would occur only if the equipment were operated with two shifts a day. A few production processes run continuously for more than one shift, so adding a shift would not increase their capacity. It would be much harder to surge production beyond 80 ppy if that proved necessary.

Increasing PF-4's capacity substantially would require changing the layout of gloveboxes and equipment. Such actions would have to comply with many regulations and other requirements; as a result, they would be time-consuming and costly. This would be true for any reorganization of space, but time and cost would in all likelihood increase as capacity in PF-4 increased, so it would probably be faster and less costly to reorganize space for 50 ppy than for 80 ppy.

Relocate a Trailer Park at Los Alamos

This option holds the potential to increase MAR permitted in PF-4 faster and at lower cost than new construction.

Los Alamos National Laboratory is located on one side of Los Alamos Canyon; the city of Los Alamos is located on the other side. The Royal Crest trailer park, with several dozen trailers, is on the lab side of the canyon. It contains the non-lab inhabited structures closest to PF-4, about 3,500 feet away. The next closest structures occupied by the public are located on Trinity Drive in the city of Los Alamos, about 6,000 feet from PF-4, and the next closest such structures after those in Los Alamos are in the city of White Rock, about five miles southeast of PF-4. **Figure 1** shows the location of Royal Crest, PF-4, and the southern portion of the city of Los Alamos.

Figure 1. Royal Crest, PF-4, Los Alamos

Source: Graphic, Google Maps; annotation, CRS.

Royal Crest is the posited location of the maximally-exposed offsite individual (MEOI), the hypothetical person outside the lab boundary who would receive the highest radiation dose from an accident in PF-4 that released plutonium. The significance is that if Royal

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(...continued)

December 2012, pp. 12, 14, https://str.llnl.gov/Dec12/pdfs/12.12.2.pdf, and David Clark, "Summary Remarks on Plutonium Aging," LA-UR-13-27541, Los Alamos National Laboratory, September 2013, p. 1.

Crest were no longer the location of the MEOI—and the road, E. Jemez, that it is on were to be placed under the control of the lab—then the next closest inhabited structure would be 2,500 feet farther away. The quantity of radioactive particles deposited per unit of area generally decreases with distance from the radioactive source because more particles are deposited closer to the source and those deposited at a greater distance are spread out over a wider area. As a result, for a wind blowing from PF-4 toward Royal Crest and Los Alamos, dose to an MEOI in Los Alamos would be expected to be less than to an MEOI at Royal Crest. Since the MAR ceiling in PF-4 depends on dose to the MEOI, reducing the dose to the MEOI would—by itself—permit increasing MAR in PF-4. Based on preliminary calculations related to the dispersion of radioactive materials from PF-4 in an accident, Los Alamos National Laboratory estimates that if the MEOI is at E. Jemez Road, dose to him or her would be reduced by 4%, and if that individual is at the southern border of Los Alamos city, dose would be reduced by 40%.[11] The reduction in dose would, if incorporated into PF-4 safety calculations, permit an increase in MAR in PF-4. If wind always blew directly from PF-4 toward Royal Crest and the city of Los Alamos, then a 40% reduction in dose would permit a 67% increase in PF-4 MAR. However, calculation of dose must factor in the probabilities of each direction the wind blows at PF-4. As a result, the increase in MAR permitted by relocating Royal Crest would be considerably less than 67%. A detailed calculation would be required to arrive at a precise figure. Nonetheless, relocating Royal Crest could permit an increase in MAR at PF-4 faster, and probably at substantially lower cost, than new construction.

Improve Modeling of Atmospheric Dispersion of Plutonium

Compared to the current calculation, using a different computer model and different assumptions on plutonium dispersion reduces calculated dose by up to orders of magnitude. This revised calculation holds the potential to permit more than doubling of PF-4 MAR quickly and at essentially no cost.[12]

NNSA calculates dose to an MEOI from an accident at PF-4 using computer models. The models use assumptions on the amount and form of plutonium released into the atmosphere, mechanisms for releasing it from PF-4, wind direction and speed, temperature, humidity, and the like. Three changes to accident modeling produce very different results than those currently assumed in the PF-4 safety documentation.

- First, LANL, consistent with guidance from NNSA, uses a particular atmospheric transport and dispersion model to calculate how much material reaches the MEOI. However, a different model that the Nuclear Regulatory Commission has used for decades, which includes "plume meander," generates a wider dispersion pattern and thus a lower dose.[13]
- Second is an assumption on how long the doors to PF-4 are open during the accident as personnel evacuate. This seemingly minor assumption is important

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[11] Information provided by Los Alamos National Laboratory, April 20, 2015.

[12] Information in this section provided by Los Alamos National Laboratory, April 2015.

[13] U.S. Nuclear Regulatory Commission, Office of Nuclear Regulatory Research, *Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants*, Regulatory Guide 1.145, November 1982, p. 1, http://pbadupws.nrc.gov/docs/ML0037/ML003740205.pdf. NRC applies this model for wind speeds of up to 6 meters per second (about 13 mph) at a height of 10 meters. Ibid., p. 3.

because less plutonium would escape if the doors were open for less time. The new calculation reduces the time that the doors are assumed to be open based on historical data during drills.[14]

- A third assumption has to do with time of day. The least dispersion of particles occurs at night, when winds are calmer. More dispersion occurs with daytime wind patterns. Greater dispersion results in a lower dose to an MEOI at any spot. Yet more plutonium is in process, and at risk, during the day, when technicians are working with it; at night, it is stored in a minimally vulnerable state. At present, the model assumes daytime MAR and nighttime dispersion. Harmonizing MAR and time of day reduces dose: at night, there is less dispersion but less plutonium that can be dispersed, reducing dose; during the day, more plutonium is at risk but an accident would disperse it more widely, reducing dose.

These three changes, plus others, in PF-4 accident modeling could reduce the calculated dose to the MEOI by several orders of magnitude. That reduction, if incorporated into PF-4's safety documents, would permit more than doubling the MAR permitted in PF-4. It would surely be faster and less costly to change to a more realistic model and assumptions than to build a new plutonium building. A more conservative model, almost by definition, produces a lower dose, though changes to reduce conservatism a model, if valid, do so as well. At issue for Congress are whether a change made to PF-4's MAR allowance in consequence of using the more realistic model would increase risk to the public and, if so, whether the benefits obtained by using that model would be worth the added risk. Public perception is also at issue: would members of the public believe that NNSA permitted the change in model in order to save money at the expense of public safety?

Remove Contaminated Equipment

This option holds the potential to reduce the risk of contamination—thereby improving worker safety and reducing risk to throughput—and to increase space available in PF-4.

The Defense Nuclear Facilities Safety Board (DNFSB) monitors health and safety issues at DOE defense nuclear facilities, and provides the President and Secretary of Energy with advice and recommendations on these issues.[15] A DNFSB report of October 2014 stated, in a section on PF-4,

> an entire wall of legacy gloveboxes, including some that housed a former incineration process for plutonium-238 contaminated rags, contains degraded conditions that workers suspect has contributed to multiple contamination events during the past few years. LANL management does not currently have a plan to remove these gloveboxes in order to both eliminate the hazard and free up the considerable space for new programmatic work.[16]

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[14] Complete collapse of PF-4 would render door opening time moot; on the other hand, the rubble generated by the collapse would contain much of the plutonium.

[15] See Defense Nuclear Facilities Safety Board, "Who We Are," http://www.dnfsb.gov/about/who-we-are.

[16] Defense Nuclear Facilities Safety Board, "Los Alamos Report for Week Ending October 10, 2014," October 10, 2014, 1 p., http://www.dnfsb.gov/sites/default/files/Board%20Activities/Reports/Site%20Rep%20Weekly%20Reports/Los%20Alamos%20National%20Laboratory/2014/wr_20141010_65.pdf.

While the amount of Pu-238 is apparently small, it is much more radioactive than Pu-239, so removing the gloveboxes would reduce MAR by a small amount. Of greater importance, removing the gloveboxes would reduce the risk of a contamination accident, which would remove a room from service until the contamination was cleaned up. Minimizing the risk of such accidents increases the availability of the room to support pit production. Removing these gloveboxes would also "free up the considerable space." The gloveboxes will have to be removed eventually for decontamination and decommissioning at the end of PF-4's life; there is a tradeoff between gaining the advantages of removing them sooner and the drawback of incurring the cost now rather than later.

Increase Material-At-Risk Ceilings by Using Conservative Rather Than Very Conservative Assumptions

This option holds the potential to increase permitted MAR in PF-4 by several orders of magnitude by using different assumptions in a calculation. While such an increase is vastly more than needed, the analysis shows how it might be possible to increase permitted MAR enough to meet mission requirements without construction. It would be faster to change assumptions than to build a new plutonium building, thereby accelerating schedule and avoiding a substantial cost.

This section highlights a tradeoff among costs, benefits, and risks. Using the most conservative assumptions provides the greatest margin of safety, but does so at the highest cost. At issue for Congress is a political judgment: for risk reduction, at what point are the marginal costs no longer worth the marginal benefits? Could funds spent for a small reduction in dose from a sequence of events occurring once in perhaps hundreds of thousands of years be more beneficially spent elsewhere?

A MAR limit is imposed uniquely for each building (except those with a very small amount of material) by a Documented Safety Analysis that is intended to limit MAR so as to ensure that the radiation dose to nearby workers and the public from such a disaster does not exceed certain limits specified by DOE. Dose is calculated for a MAR value using a ten-factor equation that includes the amount of damage the building sustains, the fraction of plutonium that is released into the atmosphere by the event, an individual's breathing rate, and others. MAR is the input variable, and dose is the resultant. Each variable is assigned a value pursuant to a DOE standard or other source. One variable, specific activity (radioactivity per unit mass), varies with the type of material (e.g., uranium, WGPu, or Pu-238). Other variables, such as breathing rate, would under most circumstances be taken as a constant. To keep dose below the specified levels, NNSA typically assigns several variables a very conservative worst-case, or "bounding," value.

In 2014, Kamiar Jamali, Associate Administrator for Safety and Health, Office of Nuclear Safety, NNSA, described the consequences of using multiple variables, each with worst-case values:

> When complex analyses are employed to derive distributions for output variables for calibration of the degree of uncertainties in analysis results, the 95th percentile is generally associated with the upper-bound. … [However,] when several input parameters are taken at their bounding values, the obtained result dwarfs the derived 95th percentile of the output by orders of magnitude.
>
> Extreme conservatism is often intentionally exercised in safety analyses because it can pay dividends in simplified analysis and review efforts. However, the search for increased conservatism cannot be pursued without consequences. Extreme conservatism can lead to

> safety conclusions and decisions with significantly higher safety costs, which can make nuclear facilities, even those with very low hazard and risk profiles, prohibitively expensive.[17]

Jamali also stated, "The mean value is proposed as the metric that is consistent with the concept of reasonable conservatism in nuclear safety analysis, as its value increases towards higher percentiles of the underlying distribution with increasing levels of uncertainty."[18] That is, the more variables in a nuclear safety equation, the closer the product of the equation moves toward (if not beyond) the 95th percentile.

Excessive conservatism has been a concern for years. In 1999, another DOE staff member wrote,

> While nuclear safety analyses must always be conservative, invoking excessive conservatisms does not provide additional margins of safety. Rather, beyond a fairly narrow point, conservatisms skew a facility's true safety envelope by exaggerating risks and creating unreasonable bounds on what is required for safety. The conservatism has itself become unreasonable. …
>
> Unreasonable conservatisms require expensive preventive or mitigative features that provide little or no real improvement in facility safety. Indeed, they are often counterproductive to real safety, diverting attention from other equipment whose actual importance to safety is greater.[19]

Another study found that the assumptions used to calculate health effects of a given dose can make a difference in the projected health effects by as much as several orders of magnitude.[20]

A catastrophe that results in all terms being at their bounding values has a much lower probability of occurring than does the initiating event. An earthquake that collapses PF-4 has a probability of occurring once in 10,000 years. But the worst-case sequence would require a complete building collapse followed by fire. The plutonium in the building would have to be in a form and condition in which it could be dispersed (e.g., spilled onto the floor as a result of a glovebox being knocked over while the plutonium was in molten form). A substantial part of that plutonium would have to be in the form of plutonium oxide particles of a size small enough to reach the lungs when inhaled, and all these particles would have to reach the atmosphere. A high wind would have to be blowing in the "right" direction to expose the MEOI to more than a negligible dose. That unfortunate individual would have to be doing moderate exercise for two hours at the spot at the site boundary that received the most deposition of plutonium. In sum, if the earthquake that initiates this sequence occurs once in 10,000 years, the concatenation of all these events would occur far less frequently. The odds of all these events occurring all at once within the service life of PF-4 are extremely low.

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[17] Kamiar Jamali, "Achieving Reasonable Conservatism in Nuclear Safety Analyses," *National Nuclear Security Administration Technical Bulletin 2014-1,* July 2014, p. 2.

[18] Ibid., p. 2.

[19] Guy Bishop III, Department of Energy, Richland Field Office, Richland, WA, "Removing Unreasonable Conservatisms in DOE Safety Analyses," paper to be presented at Safety Analysis Working Group, Portland, OR, June 13-18, 1999, DOE-0274-FP, pp. 1, 2, http://www.osti.gov/scitech/servlets/purl/782380.

[20] See Richard Chang et al., *State-of-the-Art Reactor Consequence Analyses(SOARCA) Report,* U.S. Nuclear Regulatory Commission, NUREG-1935, November 2012, pp. 78-80, http://pbadupws.nrc.gov/docs/ML1233/ML12332A057.pdf.

While desirable in an ideal world, guarding against the worst case has its costs. It requires much more stringent safety features, much more rigorous standards for equipment, and construction that is much more resistant to threats such as earthquakes. Such features drive up the cost of a building, perhaps to the point where it is no longer affordable. Alternatively, bounding assumptions might require construction of one to three modules costing perhaps $1 billion each.

An alternative is to use the expected, or median, value for each of five variables (airborne release fraction, respirable fraction, damage ratio, leak path factor, and chi/Q, as described in **Table 2**) that could readily be varied. While Jamali suggests using mean values, some DOE documents provide mean values and others provide median. For purposes of safety basis calculations applicable to LANL, however, mean and median are so close together as to be virtually indistinguishable.[21] It is reasonable to use mean or median values rather than bounding values because, as noted, use of multiple bounding values in an equation produces a result—i.e., a dose to the MEOI—orders of magnitude greater than the standard bounding value, i.e., the 95th percentile. Yet an increase in the MAR ceiling in PF-4 by a factor of less than ten, and perhaps less than two—especially when combined with other MAR reduction measures described in this report—would probably provide enough MAR to permit production of 80 pits per year in PF-4. (Meeting MAR requirements would not address space requirements.)

Increasing the MAR ceiling could also benefit analytical chemistry. The Radiological Laboratory-Utility-Office Building is ideally configured for AC, but DOE's regulations, which it has set for itself, limit "radiological facilities" like RLUOB to 38.6 g Pu-239 equivalent. About 26 g of WGPu has the radioactivity of 38.6 g of Pu-239—and the volume of two nickels. Increasing that ceiling by a factor of 40 or less might permit RLUOB to perform most of the AC needed to support production of 80 ppy.

Table 2 shows the relationship between MAR and dose and how different assumptions affect dose. Each row is an equation, with the first nine terms multiplied together to yield dose. In Equation 1, which follows DOE guidelines, a PF-4 MAR of 2,600 kilograms produces a dose to an MEOI of 166 rem in a worst-case accident. (Rem is a measure of radiation dose.) The dose would mainly result from plutonium oxide particles inhaled within two hours of the accident, but since some plutonium would remain in the body for many years, the dose would be the cumulative dose received over 50 years. In Equation 2, which uses median values, that same MAR produces a dose of 0.005 rem. Thus Equation 1 results in a MAR 35,000 times as great as in Equation 2. The same result holds for RLUOB in Equations 3 and 4.

Two scenarios illustrate the difference. Imagine that PF-4 collapsed in an earthquake and was subject to a fire. In one scenario, PF-4 has 35,000 kg of plutonium MAR and the dose to an MEOI is calculated using median values in the equation. In the other scenario, PF-4 has 1 kg of plutonium MAR and the dose to an MEOI is calculated using bounding values. The dose to the MEOI would be the same for both scenarios.

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[21] Information provided by Los Alamos National Laboratory, November 18, 2014.

Table 2. Relationship between MAR and Dose Using Very Conservative and Conservative Assumptions

Building and assumptions (bounding or median)	Variables									
	MAR	**ARF**	**RF**	**DR**	**LPF**	**chi/Q**	**BR**	**SA**	**DCF**	**Dose**
1: PF-4, bounding	2.60E+06[a]	2.00E-03[b]	0.3[b]	1[c]	1[d]	8.77E-05[e]	3.30E-04[f]	6.22E-02[g]	5.92E+07[h]	1.66E+02
2: PF-4, median or mean	2.60E+06[a]	3.00E-04[b]	0.5[b]	0.1[i]	0.1[i]	1.00E-06[i]	3.30E-04[f]	6.22E-02[g]	5.92E+07[h]	4.74E-03
3: RLUOB, bounding	4.00E+02[a]	2.00E-03[b]	0.3[b]	1[c]	1[d]	8.77E-05[e]	3.30E-04[f]	6.22E-02[g]	5.92E+07[h]	2.56E-02
4: RLUOB, median or mean	4.00E+02[a]	3.00E-04[b]	0.5[b]	0.1[i]	0.1[i]	1.00E-06[i]	3.30E-04[f]	6.22E-02[g]	5.92E+07[h]	7.29E-07

Source: CRS.

Notes:

The first nine variables are multiplied together to arrive at dose. Values are for plutonium.
Dose is for a maximally-exposed offsite individual (member of the public).
Values are for plutonium in PF-4 and RLUOB.
Bounding assumptions are very conservative; median assumptions are conservative.
Median values are used for ARF, RF, DR, and LPF; mean value, the value available in source (e), is used for chi/Q. According to Los Alamos, for purposes of safety analysis the mean and median values for this term would be almost the same.

Abbreviations:

"E," as in E+06, represents multiplication by 10 to an exponent. Thus, 2.60E+06 = 2.60 x 10^6.
MAR: Material At Risk (grams Pu-239 equivalent), MAR is specified; it is the initial input variable
ARF: Airborne Release Fraction (dimensionless fraction), fraction of MAR released by an event
RF: Respirable Fraction (dimensionless fraction), fraction of ARF particles of a size that can be inhaled
DR: Damage Ratio (dimensionless fraction), fraction of damage a building sustains
LPF: Leak Path Factor (dimensionless fraction), fraction of respirable particles that leak out of building or rubble
chi/Q: Dispersion Coefficient (seconds/cubic meter), how widely the respirable particles disperse
BR: Breathing Rate (cubic meters/second), a measured value based on research
SA: Specific Activity (curies/gram), radioactivity per unit mass, here the value for Pu-239
DCF: Dose Conversion Factor (rem/curie), converts the product of the preceding variables to rem
Dose (rem), the dependent variable, to be calculated
The **Appendix** provides further details on these terms.

Source notes for each cell:

a. MAR is specified by user

b. DOE-HDBK-3010-94 December 1994, Reaffirmed 2013: Airborne Release Fractions/Rates and Respirable Fractions for Nuclear Facilities: Volume I, Analysis of Experimental Data, page 4-9, http://energy.gov/sites/prod/files/2013/09/f2/DOE-HDBK-3010_V1_Reaffirm_2013_0.pdf

c. 1 is the bounding value, as it represents complete collapse of the structure

d. DOE-STD- 3009-94, Change Notice No. 3, March 2006, DOE Standard: Preparation Guide for U.S. Department of Energy Nonreactor Nuclear Facility Documented Safety Analyses, page A-6, http://energy.gov/sites/prod/files/2013/06/f1/doe-std-3009-94_cn3_3-30-06.pdf

e. H. Jordan, G. Smith, and R. Sartor, Consequence Calculations for Safety Analysis at TA-55 and the CMR Facility using ICRP-72 Dose Conversion Factors, LA-UR-09-07272, Los Alamos National Laboratory, November 2009, page 11

f. NNSA, Guidance on Using Release Fraction and Modern Dosimetric Information Consistently with DOE STD 1027-92*, Hazard Categorization and Accident Analysis Techniques for Compliance with DOE Order 5480.23,* *Nuclear Safety Analysis Reports,* Change Notice No. 1: Supplemental Guidance, NA-1 SD G 1027, approved 11-28-11, page 4-3, http://nnsa.energy.gov/sites/default/files/nnsa/inlinefiles/NNSA_Supp_Guide_1027.pdf

g. DOE- STD-1128-2013 April 2013: Good Practices for Occupational Radiological Protection in Plutonium Facilities, page 2-6, http://energy.gov/sites/prod/files/2013/10/f3/DOE-STD-1128-2013.pdf

h. International Commission on Radiation Protection Publication 72, Age-dependent Doses to the Members of the Public from Intake of Radionuclides - Part 5 Compilation of Ingestion and Inhalation Coefficients, page 41, September 1995

i. Information provided by Los Alamos National Laboratory, email, November 26, 2014

The March 2011 Fukushima Daiichi accident offers a concrete example of the divergence between calculated and actual effects of an accident involving radioactive release. In an article submitted in April 2012, the authors "[found] that inhalation exposure, external exposure, and ingestion exposure of the public to radioactivity may result in 15 to 1300 cancer mortalities and 24 to 2500 cancer morbidities worldwide, mostly in Japan. Exposure of workers to radioactivity at the plant is projected to result in another 2 to 12 cancer cases."[22] In contrast, a report of May 2013 by the U.N. Scientific Committee on the Effects of Atomic Radiation noted a "release, over a prolonged period, of very large amounts of radioactive material into the environment" from the accident. While those closest to the accident would have been at greatest risk, the report found

> No radiation-related deaths or acute diseases have been observed among the workers and general public exposed to radiation from the accident.
>
> The doses to the general public, both those incurred during the first year and estimated for their lifetimes, are generally low or very low. No discernible increased incidence of radiation-related health effects are expected among exposed members of the public or their descendants.[23]

Use Additive Manufacturing to Make Tooling for Pit Work

This option holds the potential to reduce turnaround time, thereby accelerating schedule, and to reduce cost.

Many see additive manufacturing (AM) as transformative for manufacturing. At issue for Congress: given the potential of AM, what applications, if any, might it have for pit production?

Additive manufacturing, often called 3-D printing, forms physical objects by depositing multiple layers of material using a "digital build file," a computer program that instructs the AM machine where to deposit the material. Objects can range from simple to so complex that they cannot be manufactured in any other way. Many analysts view AM as the future of manufacturing. According to Lawrence Livermore National Laboratory,

> Today, a metal part can be designed using computer-aided design tools and then uploaded to a machine where the part can be built layer by layer, that is, additively manufactured with

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[22] John E. Ten Hoevea and Mark Z. Jacobson, "Worldwide health effects of the Fukushima Daiichi nuclear accident," *Energy & Environmental Science,* Received 23rd April 2012, Accepted 26th June 2012, DOI: 10.1039/c2ee22019a, p. 1, http://web.stanford.edu/group/efmh/jacobson/TenHoeveEES12.pdf.

[23] United Nations, Report of the United Nations Scientific Committee on the Effects of Atomic Radiation, Sixtieth session (27-31 May 2013), General Assembly Official Records, Sixty-eighth session, Supplement No. 46, A/68/46, pp. 7, 11-12, http://www.unscear.org/docs/GAreports/A-68-46_e_V1385727.pdf.

> quality approaching that of wrought alloys. Within the next decade or two, additive manufacturing (AM) is going to completely change how we view the design and production of metal parts. AM will both replace and complement traditional manufacturing methods and reduce the time, cost, and energy consumption of producing new and existing metal parts. In order to fully implement AM, specific scientific and technical challenges must be addressed.[24]

Industry uses AM to produce complex high-precision parts that require high reliability. For example, General Electric is planning to build fuel nozzles for new jet engines using AM:

> GE chose the additive process for manufacturing the nozzles because it uses less material than conventional techniques. That reduces GE's production costs and, because it makes the parts lighter, yields significant fuel savings for airlines. Conventional techniques would require welding about 20 small pieces together, a labor-intensive process in which a high percentage of the material ends up being scrapped. Instead, the part will be built from a bed of cobalt-chromium powder. A computer-controlled laser shoots pinpoint beams onto the bed to melt the metal alloy in the desired areas, creating 20-micrometer-thick layers one by one. The process is a faster way to make complex shapes because the machines can run around the clock. And additive manufacturing in general conserves material because the printer can handle shapes that eliminate unnecessary bulk and create them without the typical waste.[25]

General Electric "is using laser-powered 3-D printers, 3-D 'inking' and 'painting' machines, and other advanced manufacturing tools to make parts and products that were thought impossible to produce … We see advanced manufacturing as the next chapter in the industrial revolution."[26]

A second example concerns AM for making large parts that undergo high stress:

> In gas turbines, the blades move at the speed of sound and heat up to 1,400°C. The elaborately shaped components are hard to design and costly to make. But Siemens, a big industrial group, is using SLM Solutions' [AM] machines to cut the cost and the time needed to replace the blades on customers' turbines when they break. It hopes eventually to cut the time from order to delivery from 44 weeks to perhaps four. …
>
> Additive manufacturing cuts the cost of tooling and materials: a piece can have all of its holes incorporated into it, with great precision, as it is built up from powder, instead of needing to have them expensively drilled afterwards. Siemens hopes to cut the cost of some parts by perhaps 30%.[27]

These examples show that AM can save time, space, and money; reduce waste; reduce the reject rate, increasing throughput; make parts on demand; and switch rapidly from making one part to making another. It can make complex parts. It can avoid some manufacturing steps, such as drilling holes, saving time and reducing the risk of error. Not all advantages apply to each product. AM is not the best manufacturing method for all materials and components, and it may

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[24] Lawrence Livermore National Laboratory, "Accelerated Certification of Additively Manufactured Metals Initiative: Metal Additive Manufacturing," 1/14/2015, https://acamm.llnl.gov.

[25] Martin LaMonica, "10 Breakthrough Technologies 2013: Additive Manufacturing," *MIT Technology Review,* April 23, 2013, http://www.technologyreview.com/featuredstory/513716/additive-manufacturing/.

[26] General Electric, "Transforming manufacturing, one layer at a time," http://www.ge.com/stories/advanced-manufacturing.

[27] "Additive Manufacturing: Heavy Metal," *The Economist,* May 3, 2014, http://www.economist.com/news/business/21601528-three-dimensional-printing-may-help-entrench-worlds-engineering-giants-heavy-metal.

not be suitable for some. But because it is adding value in many ways, it is likely to attract more R&D dollars, leading to advances that will make it applicable to a wider range of products.

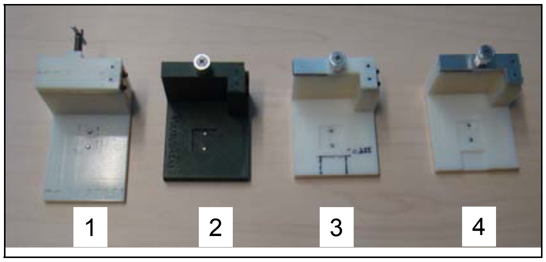
Recognizing the potential of AM to transform manufacturing, Congress, in P.L. 113-235, the Consolidated and Further Continuing Appropriations Act for FY2015, provided $12.6 million for AM for the nuclear weapons program, and the appropriations committees directed NNSA to provide "a ten-year strategic plan for using additive manufacturing to reduce costs at NNSA production facilities while meeting stringent qualification requirements."[28] The report is due to the House and Senate Committees on Appropriations 120 days after enactment of this act, which was signed into law on December 16, 2014. In late April 2015, NNSA indicated that it expects to transmit the report, which will be classified, to Congress in several weeks.[29]

NNSA is exploring applications of AM in the nuclear weapons complex. Donald Cook, Deputy Administrator for Defense Programs at NNSA, said in January 2015, "within the last year, more than half of the new fixturing within the new Kansas City National Security Campus was made with AM processes."[30] (Fixtures hold material in place for machining and inspection.) A Livermore publication states,

> A match drill fixture, the first piece of production-qualified tooling made by AM, has already entered use at Y-12. The new approach for producing this tool consolidates 5 parts into 1, thereby eliminating 12 welds and reducing waste.
>
> NNSA sites estimate that 50 percent of its tools could be made using AM in five years. In which case, tooling production costs would be reduced 75 percent, development time 80 percent, and production time 60 percent, while potentially improving tool performance. Further, the items could be printed on demand, reducing inventory and freeing space.[31]

Figure 2. Iterative Development of a Tool

Using Additive Manufacturing



Source: Sandia National Laboratories; annotation by CRS.

Figure 2 illustrates the capability of AM to develop prototypes rapidly.[32] It shows a tool, in this case a fixture for holding a part, as it moves through four iterations. Iteration 1 has a screw in the back. Iteration 2 has a shorter horizontal plate, a cutout in the vertical plate, and the screw on top, where it is easier to access. Iteration 3 uses the same material, a plastic, as iteration 2 but with a different color. The metal piece on top was made in a machine shop. The customer drew by hand where an additional indent should be. Iteration 4, with the indent, is the final tool. It

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[28] "Explanatory Statement Submitted by Mr. Rogers of Kentucky, Chairman of the House Committee on Appropriations Regarding the House Amendment to the Senate Amendment on H.R. 83," *Congressional Record*, daily edition, vol. 160, no. 151, part II (December 11, 2014), p. H9703.

[29] Email, April 23, 2015.

[30] Email, January 12, 2015.

[31] Rose Hansen, "Next-Generation Manufacturing for the Stockpile," *Science & Technology Review*, January/February 2015, p. 6, https://str.llnl.gov/content/pages/january-2015/pdf/01.15.1.pdf. A match drill fixture aligns a drill for machining.

[32] Information provided by Nathan Fuller, Mechanical Engineer, Sandia National Laboratories, emails and telephone conversations, March 3 and 9, 2015.

took two days for Sandia National Laboratories to make each iteration, for $77 apiece, as compared to 42 days for an outside machine shop to manufacture each iteration at a cost of $500 apiece.

AM parts, such as fixtures and tools, might be used in support of pit production. In some cases, they can be stronger and lighter than tools made with conventional methods. For example, AM tools can be "lightweighted," e.g., made with honeycomb in areas that do not require much strength and solid in areas that do, providing ergonomic benefit for glovebox work. AM for tooling might offer modest savings, as tooling is a minor cost of pit manufacturing, but it more likely would save time, as AM can prototype tools quickly and can make them to order. Saving time would help increase throughput. Currently, tools for pit work are made with conventional methods, which is generally satisfactory. However, Livermore notes, "very little work is being done to explore tooling used in conjunction with pit production."[33]

Use a Different Process to Fabricate Crucibles[34]

This option holds the potential to reduce risk to workers, cost, and waste, and to increase throughput.

The electrorefining process for purifying plutonium, discussed in "Discard Byproducts of Electrorefining," below, is conducted in magnesium oxide crucibles, and produces a ring of purified plutonium. To fit in a furnace, this ring must be broken into several pieces in order to be melted down for casting. This procedure has several problems:

- Crucibles are made by casting a slurry of magnesium oxide particles followed by sintering.[35] The crucibles have historically not been made as a single piece because it has been simple to make two separate cups and join the inner cup with an adhesive to the bottom of the outer cup. Sometimes, given the high heat and the reactive nature of plutonium, the adhesive fails and the cups come apart.
- A failed electrorefining run produces more waste, such as the adhesive, than a successful run, and reduces throughput and increases cost.
- The plutonium ring is broken in a glovebox located in the electrorefining area. The glovebox uses a hydraulic breaking press; the breaking operation produces chunks, shards, and grains of plutonium metal. Shards may puncture gloves used in gloveboxes, posing a risk to technicians. Shards and grains must be reprocessed through the chloride recovery line, generating waste and increasing cost. The operation adds a process step and entails worker exposure to radiation.

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[33] Email, April 3, 2015.

[34] This section is based on discussions with Los Alamos National Laboratory staff, November 2014-February 2015, Lawrence Livermore National Laboratory staff, January and April 2015, and "Plutonium Processing at Los Alamos," *Actinide Research Quarterly* (entire issue), third quarter 2008, p. 13, http://arq.lanl.gov/source/orgs/nmt/nmtdo/AQarchive/3rdQuarter08/pdf/ARQ.3.08.pdf.

[35] "Sintering is a heat treatment applied to a powder compact in order to impart strength and integrity. The temperature used for sintering is below the melting point of the major constituent of the Powder Metallurgy material. After compaction, neighbouring powder particles are held together by cold welds." "Sintering in the Powder Metallurgy Process," no author or date, *Powder Metallurgy Review,* http://www.ipmd.net/Introduction_to_powder_metallurgy/Sintering, accessed February 9, 2015. A slurry is a mixture of solid particles suspended in liquid, in this case magnesium oxide particles in water.

- The breaking press glovebox takes up space that could be used to add a metal recovery glovebox, such as an additional electrorefining station. So doing would increase the throughput of that process and support a higher pit production rate.

The United Kingdom's Atomic Weapons Establishment is conducting final development trials of a crucible that addresses these problems. It is made in one piece with ridges running from the outer wall of the inner cup to the inner wall of the outer cup in order to deposit molten purified plutonium in segments. This eliminates the need for a separate glovebox for breaking the plutonium ring and the resulting problems. The crucible is made with the same "slip casting" process used to make current crucibles. "Slip" refers to the thick water-magnesium oxide slurry. The molds are made of plaster of paris; an inner and outer mold are used to make complex shapes such as the ridged crucible. The slurry is poured between the two molds. Plaster of paris draws water out of the slurry, leaving magnesium oxide in the desired shape, which is then heated to high temperature in a furnace to sinter the magnesium oxide particles into a dense solid. These crucibles would appear to be applicable to U.S. electrorefining operations. On the other hand, development of the new crucibles is not complete, and there is no operational experience with them, so there is no guarantee that they will function properly in practice. A decision on whether to use them, or to continue using existing crucibles, must therefore await additional data.

Options Involving Process Modifications

Develop and Qualify Accident-Resistant Containers

This option holds the potential to improve worker safety, reduce MAR, and reduce risk to the public.

Radioactive material is "at risk" if it can be acted upon by an event. In the case of PF-4, "acted upon by an event" means plutonium released into the atmosphere by a worst-case accident, such as an earthquake followed by a fire. One way to reduce MAR in PF-4 is to place plutonium in containers designed to withstand an accident. If 10% of the plutonium in a container is expected to escape, as compared to all of that plutonium in a glovebox, MAR for that plutonium is reduced by 90%. The damage ratio indicates the fraction of plutonium expected to escape: for a damage ratio of 1.0, all the plutonium is expected to escape; for a damage ratio of 0.1, one-tenth is expected to escape.

To reduce MAR, the reduction in damage ratio must be credited in PF-4's Documented Safety Analysis, which, among other things, sets the ceiling on the amount of MAR allowed in PF-4. To qualify containers as having a certain damage ratio, they are subjected to intense testing, such as dropping them from a height of several meters, placing them in a pool of burning kerosene, and heating them to red-hot in an oven. Technicians measure the amount of particulate that comes out of the container after each test. The damage ratio does not apply to a complete collapse of PF-4, as containers are not expected to survive that event.

Some years ago, Los Alamos used a Hagan container, which had a damage ratio of 0.05. Since then, a newer container, a SAVY-4000, has been introduced commercially, with a damage ratio of 0.01. These containers are intended for long-term storage, not for ease of use in gloveboxes. Yet a substantial amount of plutonium on PF-4's lab space is in process. Placing more of that plutonium in containers when not in immediate use would reduce MAR on the main floor.

Examples of how broader use of qualified containers could further reduce MAR include:

- Containers could be designed for use on the pit production line, such as in gloveboxes. These containers would have to be small enough to fit in a glovebox, heavy enough to withstand severe accident conditions, and easy to open and close. They would have to be tested in various ways to confirm that they meet a certain damage ratio. Since plutonium and other radioactive materials are tracked continually in PF-4, containers on the production line would have more impact on MAR fluctuations, and the ability to stay within MAR limits, than would containers holding plutonium for long-term storage, which are seldom opened.
- Pu-238 is 277 times more radioactive than Pu-239, so while PF-4 housed less than 2 kg of Pu-238 in February 2013, it contributed about a quarter of PF-4's MAR. The main application of Pu-238 is in space probes: radioisotope thermoelectric generators convert the intense heat from its radioactive decay to electricity. Pu-238 for use in these generators is converted to a powder. This is done by ball milling, in which a piece of Pu-238 is put in a container with stainless steel shot pellets. The container is tumbled, and the pellets grind the Pu-238. Given the intense radioactivity of Pu-238, this operation is performed in a particularly robust container, which has a damage ratio of 0.01. However, the container has not been credited in the Documented Safety Analysis as having that damage ratio, so tests would have to be done and paperwork completed so it could be credited. So doing would reduce MAR in PF-4.
- Plutonium casting is a major source of MAR in PF-4, second only to Pu-238 operations. Arranging casting equipment so that plutonium is not at risk during casting would help reduce MAR in PF-4. Minimizing MAR from casting would be particularly important in a ramp-up to 80 ppy because more casting would be needed to make more pits. A concern is that, as a result of a catastrophic accident, molten plutonium could spill out into the room and could then burn, forming plutonium oxide particles that could be lofted into the air, resulting in dose to workers or the public. Conducting plutonium casting in a credited container would reduce this risk. At present, molten plutonium is poured into graphite molds to form hemishells. This operation takes place inside robust stainless steel containers attached to the bottom of gloveboxes. However, these containers have not been qualified, so the plutonium in them counts toward MAR. Upgrading the containers so they could be qualified would require a tight and sturdy lid, and the upgraded container would have to be put through various tests. A key advantage of this approach is that it is passive. It would not rely on electrical, plumbing, or other systems to function, a major advantage in the event of a catastrophic accident.

Process Plutonium Samples More Efficiently

This option holds the potential to reduce cost, MAR, space, and waste, and increase throughput.

Pit production requires a detailed characterization of plutonium at various stages, from the electrorefined product to hemishells to waste streams, to determine if the sample falls within required specifications. This characterization is done with analytical chemistry. Samples of metal for AC are taken from larger pieces of plutonium, such as purified metal produced by electrorefining and excess material from hemishell casting. These metal samples, typically 5 g each, are dissolved in acid and the resulting liquid is split into smaller samples for analysis. Many of these samples contain milligram or smaller quantities of plutonium. Samples are also taken from liquid waste, such as from nitric or hydrochloric acid processes. Rocky Flats Plant, which produced up to 2,000 ppy during the Cold War, took an average of 10.5 metal samples per pit in 1989, the year when plutonium operations at that plant halted. When LANL produced pits after Rocky Flats closed, it took an average of 12 metal samples per pit.

Most of LANL's plutonium AC is conducted in the Chemistry and Metallurgy Research (CMR) building. CMR opened in 1952 and is in poor condition. NNSA plans to halt programmatic activities there by FY2019.[36] As part of that plan, NNSA plans to move most AC from CMR to the Radiological Laboratory-Utility-Office Building. However, as noted, it is not known if RLUOB has enough space and a high enough MAR limit (even if increased to 400g Pu-239 equivalent) to conduct, along with PF-4, the AC needed to support production of 80 ppy. One way to reduce space and MAR required for AC is to reduce the number of samples per pit, or the amount of plutonium per sample. So doing would offer several advantages:

- The amount of equipment needed for AC increases, though not linearly, with number of samples. Analyzing fewer samples per pit would enable fewer pieces of equipment, and fewer gloveboxes, to support a given rate of production, reducing space requirements and cost and increasing throughput.
- Processing fewer samples per pit would increase the likelihood that RLUOB could perform most AC needed, which would reduce the AC capacity and the types of AC capabilities needed in PF-4, reducing encroachment on space there.
- Reducing the number of samples per pit would reduce the amount of waste generated per pit. This would reduce the load on AC—permitting more AC capacity to be used to support pit production—and on waste processing.
- New equipment may provide sufficient confidence with smaller samples, reducing MAR for those analyses. For example, LANL is developing techniques, using new instruments, to reduce the quantity of plutonium per AC sample from 250 mg to 50 mg for certain analyses. This reduction in MAR becomes particularly important as production rate increases.

Accepting less accurate analytic techniques may increase throughput.

- Hemishells require detailed isotopic analysis, which can take 7 to 10 working days for the "gold standard" technique (thermal ionization mass spectrometry). In contrast, samples not requiring war reserve certification, such as metal supply and recovery, could use a less precise technique (gamma ray analysis), which takes 2 to 3 days. The latter approach would also generate less waste.

The chief concern about taking fewer or smaller samples per pit or performing fewer or less accurate analyses is a reduction in precision. This concern can be addressed in several ways.

- Not all pit production process steps for which samples are taken require the highest level of precision. The final product, plutonium in hemishells, requires the greatest accuracy. Less accurate methods, or fewer samples per pit, could

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[36] U.S. Department of Energy, *FY 2016 Congressional Budget Request*, Volume 1, National Nuclear Security Administration, p. 65.

provide adequate precision for the initial supply of plutonium, because the goal would be to ensure that production processes were operating properly. Characterization of plutonium metal recovered from salts remaining after electrorefining may not require a full suite of AC with the highest accuracy because the metal would undergo further processing and characterization. Samples taken for waste processing, criticality analysis, and material control and accountability do not require the same level of accuracy as samples for weapon certification. Thus, alternative AC methods might be used or number of samples reduced for some steps.

- As pit production rate increases, fewer samples per pit taken during metal production would probably suffice to demonstrate that production processes were operating properly; the number of samples leading to final certification of a pit would presumably remain unchanged.
- Skill and experience level of personnel affect the success of analysis and production. The experience level of technicians would be expected to increase as production rate increased, which would reduce the need for rework and increase throughput of sample analysis.

Discard Byproducts of Electrorefining

This option holds the potential to reduce cost and waste, increase throughput, and make more space available.

Plutonium decays radioactively, yielding, directly or indirectly, uranium, americium, and neptunium, as detailed in **Table 4**. These, and any impurities from other sources, must be removed before plutonium can be used in pits. There are several steps in purifying plutonium for weapons use; the final step is electrorefining.

In electrorefining, an ingot of impure plutonium is placed in a small magnesium oxide crucible at the bottom center of a larger crucible of the same material. (See **Figure 3**.) The rest of both crucibles is filled with a salt mixture (sodium chloride and potassium chloride) that acts as an electrolyte. Both are melted at 740°C, well above the melting point of plutonium (639°C). An electric current is used; the anode is a tungsten rod inserted into the molten plutonium and the cathode is a circular ribbon of tungsten in the molten salt above and outside the inner ring. The current draws plutonium atoms through the salt to the cathode, where drops of metallic plutonium fall into the space between the two crucibles, forming a ring. (See **Figure 4**.) The United States has used this process for decades, so it is well characterized—a major advantage.

Figure 3. A Crucible for Electrorefining Plutonium

Source: Los Alamos National Laboratory

Notes: The diameter of the outer crucible is about 4.5 inches.

Figure 4. Electrorefined Plutonium

Source: Los Alamos National Laboratory

As plutonium is drawn from the ingot of impure plutonium, the concentration of impurities in the inner crucible increases, eventually becoming so high that the temperature is not high enough to keep the mixture remaining in the inner crucible from solidifying.[37] At that point, the reaction stops. The process produces the ring of purified plutonium and two byproducts, the remaining ingot of plutonium with impurities concentrated, called the "heel," in the inner crucible, and the salt, which retains some plutonium (here referred to as the Pu-salt mixture). The plutonium in the heel is converted to plutonium oxide; it and the Pu-salt mixture are dissolved (separately) in hydrochloric acid to recover their plutonium.

PF-4 has two "aqueous" process lines, i.e., those that involve a liquid, in this case one line that uses hydrochloric acid and another that uses nitric acid. They dissolve plutonium-bearing salts or oxide in acid, and use various processes to recover plutonium from the liquid. Aqueous recovery involves extensive MAR, space, and labor. Might it be possible to reduce this burden? **Table 3** shows the results of 653 electrorefining runs at Los Alamos from 1964 to 1977. While the data are old, the process for electrorefining plutonium has not changed much since that time, so the figures are useful as a rough order of magnitude of the products of electrorefining.

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[37] The temperature cannot be raised further because so doing would generate a substantial amount of sodium and potassium metal, which ignite when exposed to oxygen—an undesirable characteristic around plutonium.

Table 3. Kilograms of Plutonium in Products Resulting from Electrorefining

Year	No. of Runs	Anode	Salt and Crucible	Cathode	Product Ring
1964	38	17.181	13.370	0.951	85.567
1965	41	10.007	12.121	1.381	103.871
1966	25	7.567	8.379	0.953	81.050
1967	47	14.862	16.131	1.649	105.183
1968	44	10.542	14.092	1.552	103.605
1969	45	10.256	13.777	1.552	110.175
1970	56	14.369	17.535	1.862	136.598
1971	63	20.581	19.243	2.703	146.836
1972	89	26.494	28.522	3.534	215.101
1973	33	8.577	12.755	1.567	81.198
1974	54	14.439	22.439	2.036	129.608
1975	33	7.764	10.402	1.195	78.057
1976	46	11.790	12.970	2.028	121.457
1977	39	8.728	11.291	1.630	90.016
Sums	653	183.157	213.027	24.593	1568.322

Source: L.J. Mullins and A.N. Morgan, "A Review of Operating Experience at the Los Alamos Plutonium Electrorefining Facility, 1963-1977," Los Alamos National Laboratory, LA-8943, UC-25, December 1981, http://ftp.fas.org/sgp/othergov/doe/lanl/lib-www/la-pubs/00307321.pdf.

Notes: Total amount of plutonium in these products is 1,989.099 kg.

The table shows 9.2% of the plutonium left at the anode (the heel); 10.7% left in the salt and stuck to the crucible, almost all of which is in the salt; a small amount stuck to the cathode; and 78.8% purified in the product ring.

Might it be possible to discard the Pu-salt mixture, the heel, or both? So doing would lose some plutonium, but would avoid the need to use aqueous processes to recover the plutonium. The loss of plutonium would arguably not be a problem. The U.S. plutonium inventory was 95.4 metric tons as of September 2009, of which 43.4 metric tons were surplus to defense needs;[38] pits use kilogram quantities of plutonium. Secretary of Energy John Herrington said in 1988, "Plutonium, we're awash with plutonium. We have more plutonium than we need."[39] The need for plutonium has fallen since 1988 because the size of the U.S. nuclear stockpile has decreased considerably in the intervening years. Thousands of pits in storage at the Pantex Plant (TX) could be melted to purify their plutonium for use in new pits. Pits from weapons requiring new pits could similarly be recycled. At a rate of 80 ppy, existing plutonium would supply needs for many decades, if not centuries, and would do so for longer if existing pits could be used without modification in an LEP, as has been done, or if retired pits could be reused, a concept under study.

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[38] U.S. Department of Energy, *The United States Plutonium Balance, 1944-2009*, Washington, DC, June 2012, p. 2, http://nnsa.energy.gov/sites/default/files/nnsa/06-12-inlinefiles/PU%20Report%20Revised%2006-26-2012%20%28UNC%29.pdf. One metric ton is 1,000 kilograms, or 2,205 pounds.

[39] U.S. Congress, Senate Committee on Appropriations, Subcommittee on Interior and Related Agencies, *Department of the Interior and Related Agencies Appropriations for 1988*, Part 7, 100th Cong., 2nd sess., February 23, 1988 (Washington: GPO, 1988), p. 23.

The Pu-salt mixture from an electrorefining run could probably be sent directly to the Waste Isolation Pilot Plant (WIPP), the nation's underground storage repository for defense transuranic waste, once it reopens, or to another storage repository.[40] The heel could not be sent directly to WIPP, as that facility does not accept plutonium in metal form, but it could readily be converted to plutonium oxide for shipment. Plutonium-containing waste bound for WIPP must be placed in drums (similar in size to 55-gallon drums). This process is elaborate, requiring nondestructive analysis to verify the contents of each drum; material control and accountability; ensuring that each drum is compliant with limits on plutonium content, heat generation, surface dose, and so on. This process is well understood, as it has been performed thousands of times over the years. Shipping the material directly to WIPP would avoid the need to send it through aqueous processes. That would permit either a reduction in the space and MAR needed for these processes, though offset somewhat by added space and MAR needed for packaging the drums, or would permit existing equipment to process more plutonium in order to support a higher rate of pit production. It would involve more shipments to WIPP and more work at that facility, but less work at LANL. Congress may wish to consider the tradeoffs involved, and the consequences of the loss of plutonium. More generally, Congress may wish to have NNSA analyze, on a case-by-case basis, whether the benefit of recovering nuclear material from the many waste streams resulting from nuclear weapons complex activities is worth the cost.

Use Calcium Chloride for Electrorefining

This option holds the potential to reduce cost and waste, increase throughput, and make more space available.

Electrorefining using sodium chloride and potassium chloride has several problems:

- Plutonium held in salts reduces yield (fraction of total plutonium recovered as pure plutonium), increasing time, space, equipment, MAR, cost, process steps, and worker exposure required to produce a given amount of pure plutonium.
- Hydrochloric acid processing for recovering plutonium produces a substantial waste stream that requires further treatment.
- The plutonium content of this waste must be monitored with analytical chemistry techniques, adding to the workload, to provide for material control and accountability and to ensure against criticality problems (concentration of enough plutonium to create a fission reaction). The latter is a serious concern, as 21 of 22 known criticality accidents from 1953 to 1999 involved aqueous processes.[41]
- Preparing this plutonium-contaminated waste for disposition takes up space in PF-4 and elsewhere at LANL. The back end of this process, from waste generation to processing to disposition, is costly and imposes a high workload.

An alternative would be to use calcium chloride as the electrolyte. Lawrence Livermore National Laboratory (LLNL) has used this method since 1992 and the United Kingdom's Atomic Weapons

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[40] For the WIPP home page, see http://www.wipp.energy.gov/index.htm. "Transuranic" refers to elements, notably plutonium, having a higher atomic number than uranium.

[41] Thomas McLaughlin et al., *A Review of Criticality Accidents,* 2000 revision, LA-13638, Los Alamos National Laboratory, May 2000, Appendix B, Equipment Diagrams and Tabular Physical and Yield Data for the 22 Process Accidents, pp. 120-143.

Establishment (AWE) has used this method for over a decade. This approach offers several advantages.

- Compared with sodium chloride and potassium chloride, calcium chloride retains less plutonium after an electrorefining run because plutonium has different electrochemical behavior with calcium chloride, increasing the yield. As a result, fewer gloveboxes would be needed to supply a given amount of plutonium, making more space in PF-4 available, or a given number of gloveboxes could be used to support a higher rate of pit production.
- It is possible to remove plutonium, in combination with chlorine or other elements, from the calcium chloride-plutonium mixture using a "salt scrub": adding calcium metal to the mixture and heating it produces calcium chloride and plutonium metal. The latter, which is nearly twice as dense as lead, sinks to the bottom of the crucible and forms a "button" that is easily separated from the salt. Electrorefining with calcium chloride would remove more plutonium than would sodium chloride and potassium chloride, and the salt scrub would remove most of the rest of the plutonium. As a result, the salt left after the salt scrub would be expected to contain very little plutonium.[42]
- Disposing of that salt as waste would release aqueous process capacity, which could be used to recover plutonium from the "button." In this way, the equipment could produce more plutonium, supporting a higher rate of pit production.

While LLNL and AWE use this method, LANL had poor results when it tried it in the 1990s. This might have been because there was too much moisture in the calcium chloride; the salt is extremely hygroscopic (attracts and holds water molecules from the atmosphere). Alternatively, LANL might not have been able at that time to control the process so as to maximize yield. LANL plans to revisit this option. While LANL will use sodium chloride and potassium chloride when electrorefining in PF-4 resumes, it plans to convert to calcium chloride if the process can be successfully demonstrated. The process would require not only a dry atmosphere in the gloveboxes, but also a facility for producing dry calcium chloride and equipment for moving calcium chloride from production through use in dry conditions. LANL expects to draw on LLNL and AWE resources and experience in this effort.

Remove Americium from Plutonium

This option holds the potential to reduce worker exposure to radiation, to reduce MAR and cost, and to make more space available in PF-4.

Weapons-grade plutonium consists of about 94% Pu-239, the main isotope that supports a nuclear chain reaction, and several other plutonium isotopes. Each isotope undergoes radioactive decay at a rate (the half-life) particular to that isotope. With radioactive decay, each plutonium isotope becomes an isotope of a different element. Pu-241 decays much more rapidly than the other isotopes in WGPu; its half-life is 14.4 years. It decays into americium-241 (Am-241, half-life 432 years), which in turn decays into neptunium-237 (half-life 2.1 million years). All the other plutonium isotopes decay into uranium isotopes. As a result, the composition of WGPu—both the

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[42] Plutonium in the button would be impure, so it would have to be evaluated to determine if it could be processed through electrorefining.

plutonium isotopes and their decay products—changes slightly over time. **Table 4** shows the composition of WGPu, the decay products, and the approximate amount of various plutonium isotopes remaining after 50 years.

Table 4. 50-Year Decay of Isotopes in Weapons-Grade Plutonium

Plutonium isotopes in new WGPu	Half-life, years	Isotope in new WGPu, % by weight	Isotope in WGPu after 50 years, % by weight
Pu-238	87.7	0.01	0.01
Pu-239	24,110	93.77	93.64
Pu-240	6,563	6.00	5.97
Pu-241	14.35	0.20	0.02
Pu-242	373,300	0.02	0.02
Decay products			
Pu-241→Am-241	432.2	0	0.17
Am-241→Np-237	2,144,000	0	0.01
Pu-238→U-234	245,500	0	0.00
Pu-239→U-235	703,800,000	0	0.13
Pu-240→U-236	23,420,000	0	0.03
Pu-242→U-238	4,468,000,000	0	0.00
Total		100.00	100.00

Source: Los Alamos National Laboratory and CRS.

Notes: "→" means "decays to,"
Grams Am-241 per kg WGPu after 50 years: 1.72
Grams uranium isotopes per kg WGPu after 50 years: 1.67

The main reason to remove americium-241 is that it is an intense emitter of gamma rays. Workers handling aged WGPu in gloveboxes have only their gloves to protect them, so the main gamma ray dose they receive is to their hands. This dose can be the limiting factor in how many days per year federal regulations and LANL policies permit them to handle plutonium while staying within dose guidelines.

Purifying plutonium for weapons use involves several chemical processes. (These processes do not alter the isotopic composition of plutonium.) Electrorefining, for example, produces pure plutonium, but does not work efficiently for plutonium with a large fraction of impurities because the impurities stop the electrorefining process while much of the plutonium remains unpurified. Another process, metal chlorination, removes most americium but leaves uranium, neptunium, alloying material, and any other impurities. Metal chlorination involves bubbling chlorine gas through molten impure plutonium. This produces a salt, americium chloride, that captures almost all the americium from the plutonium. Chlorine also forms another salt, plutonium chloride. These salts form a crust, which is easily removed, on top of the plutonium metal. This metal, which includes uranium and neptunium, can then be processed through electrorefining. The salt crust contains about 90% plutonium chloride; this plutonium is recovered by dissolving the crust in hydrochloric acid and using several other process steps.

Of the Pu-241 in newly produced WGPu, 89% will have decayed into Am-241 after 50 years. U.S. WGPu is quite old. Some was produced during the Manhattan Project of World War II; most was produced between 1956 and 1970.[43] When newly produced, it had essentially no radioactive impurities; plutonium that has been purified since then has, in effect, had its age reset to zero, albeit with a slightly different mix of plutonium isotopes. As of September 2009, the United States had produced or acquired 111.7 metric tons (MT) of plutonium, an inventory of 95.4 MT, 14.0 MT removed from inventory, and an "inventory difference" (production and acquisition minus inventory and removals) of 2.4 MT.[44] Further, "there remain uncertainties about how much plutonium was actually produced, processed, and discarded to waste, especially for the period from the mid-1940s to 1970."[45] Accordingly, there is no official unclassified figure (and perhaps no classified figure) for the average age of plutonium remaining in the DOE inventory. It appears, however, based on preliminary calculations by Los Alamos, that the average age of that plutonium is about 50 years.

Because of radioactive decay, little Pu-241 is left to form additional Am-241 after 50 years. Since Pu-241 decay is the only source of Am-241, after passing aged plutonium through a final run of metal chlorination to remove Am-241, so little Pu-241 would remain that even if all of it decayed to Am-241, the latter would never reach the level found in 30-year-old WGPu, and the weapons laboratories have certified weapons with pits that old (and older) as acceptable for use in the stockpile. This final run would have two results. First, it would greatly reduce worker exposure to gamma radiation. Second, since additional runs of metal chlorination would not be needed for WGPu thus processed, the metal chlorination line could be reduced in capacity, reducing space and operating cost. (The line could not be eliminated entirely because it would be needed if, for example, a batch of old pits was sent to Los Alamos for purification.)

Accept More Uranium in Weapons-Grade Plutonium

This option holds the potential to reduce cost and space and increase throughput.

Pu-241 has the shortest half-life of the plutonium isotopes in WGPu. The others have half-lives ranging from 87.7 years for Pu-238 to 373,000 years for Pu-242. Pu-239, which accounts for 94%

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[43] These figures are based on U.S. Department of Energy. *Plutonium: The First 50 Years. United States Plutonium Production, Acquisition, and Utilization from 1944 to 1994,* available at http://fissilematerials.org/library/doe96.pdf. Pages 29 and 33 show plutonium production, by year, WWII-1988. The United States had two sites that produced weapons-grade plutonium in ton quantities, Hanford (WA) and Savannah River Site (SC), with production ending in 1988. Page 29 of the DOE report has a table that splits plutonium production at Hanford into WGPu and fuel-grade plutonium. Page 33 has a table that shows plutonium production at Savannah River Site; The report, pages 30-31, states, "The Savannah River reactors produced primarily weapon grade plutonium with a Pu-240 content of about 6 percent. Starting in 1981, to increase the availability of plutonium for the weapons program, the Savannah River P, K, C-Reactors were operated to produce weapon grade plutonium with a 3 percent Pu-240 content. This method of operating accelerated reactor operations, decreased target irradiation time, and increased fuel throughput." Assuming all Savannah River Site plutonium is WGPu, the United States had produced 6.9% of its WGPu through 1955, and 79.9% through 1970. If 80% of Savannah River production were WGPu, then 81.8% of total WGPu would have been produced through 1970.

[44] U.S. Department of Energy, *The United States Plutonium Balance, 1944-2009,* p. 4.

[45] Ibid., p. 3.

of the plutonium in WGPu, has a half-life of 24,110 years. As a result, uranium ingrowth will continue for many thousands of years. ("Ingrowth" refers to decay products that remain in the plutonium.) A concern is that a change in the composition of WGPu could affect its performance during implosion. After 50 years, uranium ingrowth accounts for 0.17% of WGPu, and ingrowth will continue at this rate, declining only slightly, for millennia. Further, 79% of the uranium ingrowth will be U-235; that fissile isotope has also been used in nuclear weapons, though it is not as effective (in terms of explosive yield per kg) as WGPu.

At issue is whether newly fabricated pits can use plutonium that has not been purified for several decades, despite the ingrowth of uranium. Some weapons in the U.S. stockpile are old. For example, the first B61 bomb was produced in 1966. The last year in which the United States made war reserve pits, excepting 29 for the W88 warhead, was 1989. NNSA plans a B61 life extension program (LEP), with the first production unit expected in FY2020. Thus, while some versions of the B61 were produced after 1989, the newest pit in B61s would, in 2020, be at least 30 years old. Yet the LEP is to use existing pits, and weapon designers expect to be able to certify the performance of life-extended B61 bombs. Similarly, the W76 warhead was first manufactured in 1978 and is now undergoing an LEP that does not use new pits. A 2007 report by the JASON group evaluated studies on pit lifetime performed by Los Alamos and Lawrence Livermore National Laboratories. The JASON report found,

> Most primary types have credible minimum lifetimes in excess of 100 years as regards aging of plutonium; those with assessed minimum lifetimes of 100 years or less have clear mitigation paths that are proposed and/or being implemented. … As a result of the Los Alamos/Livermore efforts, JASON concludes that there is no evidence from the [underground nuclear testing] analyses for plutonium aging mechanisms affecting primary performance on timescales of a century or less in ways that would be detrimental to the enduring stockpile.[46]

Thus there may not be a need to conduct electrorefining to purify plutonium for pits for decades. Further, there may be a benefit from delaying plutonium purification. Livermore notes a difference between uranium in aged pits and in pits made from purified plutonium:

> The uranium present in existing pits is formed within the plutonium lattice and does not significantly affect the nuclear or mechanical properties of the plutonium. Therefore, uranium ingrowth in existing plutonium containing pits is not considered an issue. However, if the plutonium is recovered from an existing weapon and recast, the uranium is likely to go to the plutonium grain boundaries which may affect the mechanical properties.[47]

There is thus a tradeoff between the advantages of purifying aged plutonium to remove Am-241, as discussed in "Remove Americium from Plutonium," and delaying purification.

Capacity and space could be further reduced if weapon designers were willing to accept a larger maximum allowable uranium content in the WGPu specification. Acceptance would depend on detailed studies of metallurgical and other properties of WGPu with levels of uranium isotopes that are in existing pits. If the study results proved acceptable, electrorefining capacity and space could be reduced.

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[46] R.J. Hemley et al., "Pit Lifetime," JASON, The MITRE Corporation, JSR-06-335, January 11, 2007, p. 1, http://fas.org/irp/agency/dod/jason/pit.pdf.

[47] Email, April 3, 2015.

Use Near Net Shape Casting to Fabricate Hemishells

This option holds the potential to reduce MAR, waste, and cost.

A hemishell may be visualized as a "bowl" made of plutonium. The current method to cast hemishells involves pouring molten plutonium between an inner and outer mold. When the plutonium solidifies, the molds are separated and the cast part is removed. The part is then heat-treated to impart the required material properties. It is then machined to final dimension.

The cast part, before machining, is necessarily thicker than the hemishell. Machining it produces plutonium chips. If these chips are to be recycled for use in subsequent pits, they would have to undergo purification processes, such as metal chlorination and electrorefining. Alternatively, they could be converted to plutonium oxide and sent to WIPP.

Near net shape casting (NNSC) simply has a thinner space between the inner and outer molds, and the molds produce a cast part much closer to final dimension. Otherwise, the processing (casting, heat treating, machining, etc.) is the same.

The thinner space between molds reduces the amount of plutonium needed for casting, reducing the amount of plutonium that must be machined away to produce the hemishell. On the other hand, a thinner cast part could result in a higher reject rate, as there would be less margin for error in machining. To offset this disadvantage, NNSC could use various electronic techniques to align the part more precisely and remove excess material more precisely. One such technique is in-process inspection. With traditional casting, hemishells are measured after they are machined to determine if they meet dimensional specifications. With in-process inspection, hemishells could be measured and, if necessary, realigned while in production, such as after each pass of a cutting machine, allowing the technician to compensate for errors while there was some excess material.

Current equipment is adequate to purify enough plutonium to support low production rates. The critical advantage of NNSC would come into play with higher pit production rates, when the supply of purified plutonium would become a major bottleneck. NNSC would use less plutonium per hemishell, and would produce less scrap that must be recycled. As a result, it would place less demand on the existing plutonium purification equipment, enabling it to support a higher production rate. Reducing the amount of purified plutonium per pit would also reduce the waste stream, such as the plutonium-contaminated acids and salts from purification processes. This reduction is another advantage given the cost, effort, and procedural requirements of processing radioactive waste. Using less plutonium per pit would reduce the burden on material control and accountability: less material results in less material to be accounted for, saving time and effort. Using less plutonium per pit would also reduce, on a per-pit basis, worker exposure, MAR, and cost. It would not save space, but since each pit would require less plutonium, it would allow existing equipment, in the existing space, to provide plutonium for a higher rate of pit production.

LANL has conducted some R&D into NNSC using gravity feed and plans to use this method in the future if it proves successful. It is included in LANL's planning basis for future pit manufacture. Manufacture could include new pits for certain LEPs and new pits to replace pits destroyed during surveillance. Livermore worked on developing NNSC as early as 1994.[48] It has

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[48] "LLNL Casting Technology," by Arthur B. Shapiro and William J. Comfort, III, Technical Editors, UCRL-ID-116320, January 1994, p. 5, http://www.osti.gov/scitech/servlets/purl/10133336/.

demonstrated NNSC using plutonium die casting, in which molten plutonium is forced into the space between an inner and outer mold. Livermore states, "Die casting technology is another approach to significantly reduce the amount of plutonium required per casting and therefore, the amount of feed metal."[49]

Options Involving Structural Modifications to PF-4

Augment Seismic Resilience of PF-4

This option would increase permitted MAR, worker safety, and public safety.

PF-4 became operational in 1978; since then, seismic studies have shown a greater threat to the building than was envisioned when it was designed. For example, an older model assumed that an earthquake would shake the building, while a newer model treated an earthquake as a wave of earth moving toward PF-4 that could push the building over. As a result of these studies, concern grew that PF-4 could collapse in a major earthquake:

> In public comments at a Capitol Hill Club event this summer [2013], DNFSB member Jack Mansfield explained the Board's concerns. The [PF-4] facility, built in the late 1970s, is "brittle," Mansfield said. "It was discovered after this facility was built that large buildings, to be survivable in serious earthquakes, have to have a bit of ductility. It was also discovered after the Loma Prieta earthquake that round columns, if accelerated up into the plywood they support, crumble. Those two vulnerabilities were identified early, but they're not built into PF-4."
>
> He added: "The result is that there is a probability, albeit small, that the building could collapse, with great loss of life within and with dispersal of plutonium." Previous upgrades were based on calculations that did not fully characterize the problems facing the facility, Mansfield said. Those calculations were "very good" and "did a lot," Mansfield said, but "the problem is that any of the columns, crushed like the ones on the highway did—the whole roof would go down like a zipper."[50]

To reduce the dose resulting from an earthquake that collapsed the building, followed by a fire that lofted plutonium oxide particles into the air, LANL reduced PF-4's MAR allowance for the main (laboratory) floor in 2013 from 2,600 kg of plutonium to 1,800 kg. To increase MAR, reduce potential dose, and reduce the risk of collapse, LANL is taking steps to protect PF-4 against collapse and fire.

To strengthen PF-4 against seismic shaking, LANL added a drag strut to the roof, among other things, as described in more detail in CRS Report R43685, *Manufacturing Nuclear Weapon "Pits": A Decisionmaking Approach for Congress*. (A drag strut gathers lateral forces from a large flat surface and transmits them to a shear wall, which is designed to resist those forces.) Other steps were taken to strengthen PF-4 against pushover. Many columns that run from the basement to the roof support PF-4. Some of these columns run through the vault, which holds a

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[49] Email, April 3, 2015.

[50] Todd Jacobson, "DOE Says Alternate Analysis of PF-4 Seismic Risks Will Be Done in Dec.," Nuclear *Weapons & Materials Monitor,* September 6, 2013, http://www.lasg.org/press/2013/NWMM_6Sep2013.html.

large quantity of plutonium, in the basement. These columns are held rigidly in place by the vault ceiling and are not free to move, making them more vulnerable to shear forces that could cause them to collapse. Their collapse could result in massive pieces of concrete and steel crashing through the vault ceiling, killing workers and releasing plutonium. To strengthen the columns, LANL wrapped them in carbon fiber sealed with epoxy, a measure completed in February 2014. LANL is now working to strengthen the ties between girders, which are located above the laboratory floor of PF-4, and other structural elements. As with columns, collapse of girders onto the laboratory floor could kill workers and release plutonium.

Structural upgrades to PF-4 can make a very large difference in the amount of plutonium released in a major earthquake. An NNSA accident analysis of PF-4 in June 2011

> evaluated the effect of a combined earthquake, fire, and partial building collapse. The calculated radiation dose to the hypothetical maximally exposed off-site individual (MEOI) was conservatively estimated to be 2,100 rem Total Effective Dose Equivalent1 (TEDE) for a postulated once-in-5,000-year accident (Case 1). By October 2011, PF-4 was structurally upgraded, reducing the calculated MEOI dose to 143 rem once-in-2,000 years (mitigated, Case 2). By April 2012, additional repairs will be completed that protect PF-4 safety basis assumptions and reduce the calculated MEOI dose to less than 25 rem TEDE.[51]

LANL has taken steps to reduce the risk of fire. For example, it removed about 20 tons of combustible material from PF-4, mostly from the laboratory floor.[52] It is planning to enhance the capability of the fire water loop to protect PF-4. This loop includes two 40,000-gallon water tanks, two pump houses, and an underground pipe loop that carries water to buildings in TA-55 for fire suppression. (Technical Area 55, or TA-55, is the main area at LANL for plutonium work; it consists of PF-4 and supporting buildings.) Some buildings in TA-55 are not seismically qualified, and would be more likely than PF-4 to collapse in an earthquake. If they collapsed or began to burn, water from the tanks would flow to them, reducing or eliminating the amount available for PF-4. LANL proposes to decouple these buildings from the loop and provide them with their own separate fire water supply. The Consolidated and Further Continuing Appropriations Act, 2015, P.L. 113-235, provides $1,000,000 for TA-55 seismic safety mitigation for FY2015.[53]

Build One Module for Plutonium-238 Work

This option would make more space and MAR available in PF-4, and holds the potential to reduce risk to the public.

Pu-238 is 277 times more radioactive than Pu-239, the fissile material in weapons-grade plutonium. It is so radioactive that energy from its radioactive decays generates enough heat to

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[51] Letter from Donald L. Cook, Deputy Administrator for Defense Programs, to The Honorable Peter S. Winokur, Chairman, Defense Nuclear Facilities Safety Board, January 30, 2012, Enclosure 1, p. 1, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Letters/2012/ltr_2012130_18446_0.pdf.

[52] Letter from Donald Cook, Deputy Administrator for Defense Programs, National Nuclear Security Administration, to Peter Winokur, Chairman, Defense Nuclear Facilities Safety Board, January 30, 2012, Enclosure 2, p. 1, http://www.dnfsb.gov/sites/default/files/Board%20Activities/Letters/2012/ltr_2012130_18446_0.pdf.

[53] Explanatory Statement Submitted by Mr. Rogers of Kentucky, Chairman of the House Committee on Appropriations, Regarding the House Amendment to the Senate Amendment on H.R. 83, *Congressional Record*, daily edition, vol. 160, part no. 151—book II (December 11, 2014), p. H9703.

make a small quantity, even 200 grams, glow red. It is used in deep space probes, where its heat is used to generate electricity. It has some military applications but is not used in pits.

As of February 27, 2013, before most of its operations were suspended, PF-4 held about 1.6 kg of Pu-238, but because of its high radioactivity it accounted for 24.5% of the building's MAR, or 441 kg of Pu-239 equivalent. For comparison, pit fabrication accounted for 26.4% of the building's MAR. In addition, Pu-238 programs accounted for 9,600 square feet, or 16%, of PF-4 laboratory floor space.

One approach to providing more MAR and space in PF-4 for pit fabrication is to build modules, buried reinforced-concrete structures with about 5,000 square feet of lab space connected to PF-4 by tunnels. As stated in the FY2016 DOE budget request, "NNSA is planning to construct not less than two modular structures that will achieve full operating capability not later than 2027."[54]

However, Pu-238 is not uniformly distributed within the space for Pu-238 programs. If some Pu-238 work were moved to a 5,000-square foot module, that module could accommodate most of the Pu-238-related MAR from PF-4, making that same amount of MAR and space available for pit production or other plutonium work. Thus one module for Pu-238 might suffice to enable pit production within PF-4.

Building one module may offer other advantages. It would provide experience and lessons that could help reduce cost if additional modules were built at LANL or elsewhere in the nuclear weapons complex. In particular, a review of the Uranium Processing Facility at the Y-12 National Security Complex recommended against what it called a "big box" approach in which all capabilities would be placed in one large building, and instead favored perhaps four smaller "new builds."[55] Further reducing cost if multiple modules were to be built, modules as envisioned would have a basic design, and each module would be customized with only the equipment and capabilities needed for its specific mission and hazards. In contrast, a large multi-mission building would need all features needed for any one mission, adding cost, and it would probably cost less to fix a problem in subsequent modules after building one than to retrofit a big box building. NNSA also states that modules also offer "the potential to scale facility acquisition to appropriations and adapt more quickly to changes in program requirements."[56] Since the module would be buried, it would be expected to contain plutonium better than PF-4 in the event of an earthquake, reducing risk to the public. On the other hand, some lessons from building a module might increase cost. For example, if it turned out that there was a design flaw, that modules needed to be larger, or that more concrete was needed, the second module could be more expensive than initial construction (excluding retrofits) of the first. Also at issue is whether other measures to increase MAR and space margin, such as those discussed in this report, might provide enough margin without building any modules.

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[54] U.S. Department of Energy, *FY 2016 Congressional Budget Request*, Volume 1, National Nuclear Security Administration, p. 239.

[55] Thom Mason, Chair, Committee to Recommend Alternatives to the Uranium Processing Facility Plan in Meeting the Nation's Enriched Uranium Strategy, *Final Report of the Committee to Recommend Alternatives to the Uranium Processing Facility Plan in Meeting the Nation's Enriched Uranium Strategy,* April 15, 2014, p. 7, http://www.nnsa.energy.gov/sites/default/files/nnsa/05-14-inlinefiles/Uranium_Review_Final_Report_unclassified_withappendices.pdf.

[56] Email, April 17, 2015.

Conclusion: Choosing a Package of Options

This report shows options, many of which NNSA and its labs are pursuing, that can help move toward enough capacity to manufacture pits at a rate of 80 per year. One option by itself will not provide the capacity to manufacture pits at that rate. As a result, NNSA faces the prospect of assembling a package of options, whether from the ones presented here or others, and Congress faces the prospect of evaluating, perhaps amending, and approving it. Any package chosen would need to optimize among such goals as margin, cost, worker safety, and throughput. Questions and tradeoffs to consider in formulating a package include the following:

- MAR reduction techniques include seismic strengthening of PF-4, using special containers to hold plutonium not in use, and removing contaminated gloveboxes. Would all such techniques need to be implemented, or would some, by themselves, provide enough MAR margin?
- Relocating the Royal Crest trailer park could also reduce the need for these techniques. Conversely, some of these techniques might provide more MAR margin than relocating Royal Crest, though perhaps at higher cost.
- Using a different wind model and more realistic assumptions could result in a calculated dose reduction by more than half in the event of a major accident at PF-4, permitting more than doubling the MAR allowance for PF-4 quickly and at essentially no cost, producing more MAR allowance than relocating Royal Crest. But would a doubling of the MAR allowance suffice? If not, what combination of measures that increased MAR allowance would do so?
- Techniques to increase space margin include removing contaminated gloveboxes, setting up a production line able to make 50 ppy with one shift per day and operating it with two shifts per day, and building a module for Pu-238 work. Which combination of techniques would be most cost-effective?
- Building a module, whether at Los Alamos or elsewhere, for Pu-238 work would move a substantial amount of MAR out of PF-4 and would free up some space there as well. Would that module be cost-effective, or would other alternatives provide enough space and MAR margin so as to render the module unnecessary? Or would other advantages argue for building a Pu-238 module even if sufficient margin could be obtained by other means?
- Using calcium chloride instead of sodium chloride and potassium chloride in electrorefining would reduce the amount of plutonium to be recovered through aqueous processes; near net shape casting would do so as well. Both together may permit a reduction in the space needed for aqueous processes, and a reduction in MAR as well, since aqueous processes are high in MAR.
- Alternatively, would it be cost-effective to recover the plutonium remaining in the salt and in the ingot of impure plutonium after electrorefining runs? If not, these materials could be packaged and shipped to WIPP.
- Some techniques offer increases in both space margin and MAR margin, such as removing contaminated gloveboxes.
- Some techniques may increase margin at little or no cost, and may provide savings. Using conservative rather than very conservative assumptions in

> calculating dose could reduce the need for costly physical changes, such as construction or procurement. The cost to remove contaminated gloveboxes is essentially zero, as the boxes would need to be removed at the end of PF-4's life, and removing them would avoid the risk of contamination accidents that are costly and time-consuming to clean up.

In sum, while arriving at a satisfactory package will require complex analyses, many options offer the potential to boost U.S. pit production capacity toward, if not to, the congressionally mandated capacity of 80 pits per year.

Appendix. Explanation of Terms in Table 2

Terms are listed in the order in which they appear in **Table 2**.

Material At Risk (MAR): The amount of material, in this case plutonium, acted upon by an event. It is measured in units of grams of Pu-239 equivalent, a standard used to compare the radioactivity of diverse materials.

Airborne Release Fraction (ARF): The fraction of Material At Risk released into the air as a result of the event. ARF is specific to the type of material (e.g., plutonium oxide, plutonium metal, plutonium in solution).

Respirable Fraction (RF): The fraction of the material released into the air that is of a particle size (3 microns in diameter or less for plutonium oxide) that, when inhaled, remains in the lungs. An RF of 1 represents the worst case.

Damage Ratio (DR): The amount of damage to a structure or container, with 0 being no damage and 1 being complete collapse. A DR of 1 represents the worst case, complete collapse of PF-4 or full destruction of a container.

Leak Path Factor (LPF): The fraction of material that escapes the building; even if a building or container was fully destroyed, not all material would necessarily be released into the air. While ARF is related to material type, LPF is related to engineered containment mechanisms, such as robust containers. An LPF of 1 represents the worst case (i.e., no containment is assumed).

Chi/Q: The rate at which plutonium particles are deposited (fall to the ground). It includes such factors as wind speed, wind direction, and distance from the facility to the individual receiving the dose.

Breathing Rate (BR): The volume of air, in cubic meters per second, that an individual breathes in. This is important in calculating dose because the more air an individual breathes in, other things being constant, the higher the dose.

Specific Activity (SA): A measure of the radioactivity of a material, expressed in curies (a measure of the number of radioactive disintegrations per second) per gram of material. **Table 2** shows SA for Pu-239.

Dose Conversion Factor (DCF): Multiplying SA by this factor converts SA to dose.

Dose is expressed in rem, a measure of ionizing radiation absorbed by human tissue.

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In Brief: Options to Help Meet a Congressional Requirement for Nuclear Weapon "Pit" Production

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Summary

A pit is the plutonium core of a thermonuclear weapon. Imploding it with conventional explosives provides the energy to detonate the rest of the weapon. The Rocky Flats Plant made up to 2,000 pits per year (ppy) through 1989; since then, the United States has made 29 pits for the stockpile. Yet the FY2015 National Defense Authorization Act requires the National Nuclear Security Administration (NNSA), which manages the nuclear weapons program, to produce at a rate of 80 ppy for 90 days in 2027. How can that requirement be met?

Pits are to be made at Los Alamos National Laboratory's main plutonium facility, PF-4. To manufacture pits, a facility must have enough laboratory floor space and a high enough limit for Material At Risk (MAR), the amount of radioactive material a worst-case accident could release. Producing 80 ppy requires enough "margin," the space or MAR available to produce pits minus space or MAR required for that production rate. While space and MAR available have been calculated, amounts required to produce 80 ppy have never been calculated rigorously, leaving space and MAR needs undefined. Although CRS cannot address whether certain options could meet the 2027 date because time to implement them cannot be determined, this report presents 16 options that seek to increase the feasibility of producing 80 ppy by 2027, including:

- The radiation dose an individual would receive from a worst-case accident determines MAR permitted in PF-4. A ten-factor equation calculates dose as a function of MAR. NNSA uses worst-case values in this equation, yet median values may provide sufficient conservatism. Median values reduce calculated dose by orders of magnitude, permitting a large increase in PF-4 MAR. Yet merely doubling permitted MAR might suffice for producing 80 ppy. Providing this increase through construction at PF-4 could be costly and take years.
- In determining MAR for PF-4, the closest offsite individual is at a nearby trailer park. Relocating it would place the next closest individual farther away. The added distance would reduce dose, permitting increased MAR in PF-4.
- Using a different meteorological model and different assumptions would greatly reduce the currently calculated dose, perhaps permitting doubling PF-4 MAR.
- Plutonium decays radioactively, creating elements that various processes remove to purify plutonium. One process generates byproducts; plutonium is recovered from them with processes that take space and MAR. Since the United States has tons of plutonium surplus to defense needs, byproducts could be dispositioned as waste.
- Pits use weapons-grade plutonium (WGPu). U.S. WGPu is about 50 years old. About nine-tenths of plutonium-241, a WGPu isotope, decays to americium-241 in that time. Since plutonium-241 is the source of americium-241 in WGPu, removing the current americium-241 would prevent WGPu from ever reaching its americium-241 limit, permitting reduction in equipment for that process and reducing worker radiation exposure.
- A plutonium isotope used in space probes, plutonium-238, is extremely radioactive. It accounts for a small quantity of PF-4 plutonium but a quarter of PF-4's MAR. Building a "module" near PF-4 for plutonium-238 work would free MAR and space in PF-4, so one module might suffice instead of two or three.

- To reduce risk of collapse, loss of life, and radiation release from an earthquake, NNSA increased the seismic resilience of PF-4. More steps are planned; more could be taken.

Many options may boost U.S. pit production capacity, but none by itself could meet capacity and schedule requirements. NNSA therefore faces the prospect of assembling a package of options, and Congress faces the prospect of evaluating, perhaps amending, and approving it. Arriving at a satisfactory package will require complex analyses to optimize among such goals as margin, cost, worker safety, and throughput. At issue for Congress: What are the risks, costs, and benefits of the options? What is the optimum package?

This report is a condensed version of CRS Report R44033, *Nuclear Weapon "Pit" Production: Options to Help Meet a Congressional Requirement*, by Jonathan E. Medalia.

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Introduction

A "pit" is the core of the primary stage of a thermonuclear weapon. Its key ingredient is weapons-grade plutonium (WGPu), which is composed mainly of the fissile isotope plutonium-239 (Pu-239). Detonating the pit provides the energy to detonate a weapon's secondary stage. During the Cold War, the Rocky Flats Plant (CO) made up to 2,000 pits accepted for use in the stockpile per year. Production at Rocky Flats halted in 1989. Since then, the United States has made 29 such pits in total. Yet the Department of Defense (DOD) stated it needed the National Nuclear Security Administration (NNSA), the separately organized agency within the Department of Energy (DOE) that maintains the U.S. nuclear stockpile, to have the capacity to produce 50 to 80 pits per year (ppy). Pits are to be made at Los Alamos National Laboratory (LANL, NM) in the PF-4 building, potentially in proposed smaller structures called modules connected to PF-4 by tunnels, or in both. Pits are made by casting two hemishells, or half-pits, then welding them together. In Section 3112 of P.L. 113-291, the Carl Levin and Howard P. "Buck" McKeon National Defense Authorization Act for Fiscal Year 2015, Congress directed NNSA to demonstrate the capacity to produce at a rate of 80 ppy for at least a 90-day period in 2027. Accordingly, this report takes as its focus how to move toward that requirement.

Producing 80 ppy requires enough "Material At Risk" (MAR) and space. DOE defines MAR as "the amount of radioactive materials … available to be acted on by a given physical stress," such as an earthquake. It is measured in units of Pu-239 equivalent (PE). Space is laboratory floor space available for plutonium operations. This report uses "margin" to measure "enough." Margin is space available for pit production and supporting tasks minus space required for them to be able to produce at a specified rate, and MAR available for pit production and supporting tasks minus MAR required for them to do so. Space and MAR margins are separate; both must be greater than zero to produce pits at the specified rate. MAR and space also figure in analytical chemistry (AC), a production support function. AC determines the composition of very small samples of plutonium. The Radiological Laboratory-Utility-Office Building (RLUOB), which was completed in 2010 and is near PF-4, is to house most AC.

There are figures for available space and MAR, but *figures for space and MAR required to produce 80 ppy have never been calculated rigorously,* so this report cannot determine what options would provide *enough* margin for producing 80 ppy. Nor can it address whether certain options could meet the 2027 date because time to implement them cannot be determined. Instead, the report presents 16 options that increase the feasibility of producing at a rate of 80 ppy rate by 2027. A decision will likely weigh such factors as margin, cost, schedule, throughput, and safety.

Sixteen Options

Options Not Involving Process Modifications

Install Equipment with a Single-Shift Capacity of 50 ppy

DOD stated a need for NNSA to have a capacity to manufacture 50 to 80 ppy, and Los Alamos "estimates that a second shift would increase pit-manufacturing capacity by 60% so that establishing a 50-ppy capacity could supply 80 ppy using a second shift." Further, NNSA deferred to FY2030 the projected delivery of the first production unit of the warhead that might be the first to use a newly manufactured pit since 2011; certain retired pits might prove suitable for reuse, reducing the number of newly manufactured pits needed; and pit lifetime might be longer than currently expected. Thus equipment to produce 50 ppy with a single shift might meet the 80-ppy requirement with less cost and space than equipment to manufacture 80 ppy with a single shift because less equipment would be needed. On the other hand, a higher operating tempo would place more strain on the equipment while allowing less time to maintain and repair it, though this disadvantage would occur only with double-shift operations. A few production processes run continuously for more than one shift, so adding a shift would not increase their capacity. It would be harder to surge production beyond 80 ppy if necessary.

Relocate a Trailer Park at Los Alamos

LANL is on one side of Los Alamos Canyon; the city of Los Alamos is located on the other side. The Royal Crest trailer park, with several dozen trailers, is on the lab side. It contains the non-lab publicly accessible structures closest to PF-4, about 3,500 feet away. The next closest structures accessible by the public are in the city of Los Alamos, about 6,000 feet from PF-4, and the next closest such structures after those in Los Alamos are in White Rock, about five miles from PF-4.

Royal Crest is the location of the maximally-exposed offsite individual (MEOI), the hypothetical person outside the lab boundary who would receive the highest radiation dose from an accident in PF-4 that released plutonium. If Royal Crest were no longer the location of the MEOI, and the road it is on were controlled by the lab so the MEOI was not on that road, the next closest accessible structure would be farther away. Typically, fewer radioactive particles are deposited per unit of area as distance increases, so dose to an MEOI would be expected to be less in Los Alamos than Royal Crest. Since the MAR ceiling in PF-4 depends on dose to the MEOI, reducing the dose to the MEOI would permit increasing MAR in PF-4. Relocating Royal Crest could permit an increase in MAR at PF-4 faster, and probably at less cost, than new construction.

Improve Modeling of Atmospheric Dispersion of Plutonium

NNSA calculates dose to an MEOI from an accident at PF-4 using computer models. The models use assumptions on the amount and form of plutonium released into the atmosphere, mechanisms for releasing it from PF-4, wind direction and speed, temperature, humidity, and the like. Three changes to accident modeling might be made. First, use a different atmospheric transport and dispersion model. Second, assume, based on historical data during drills, that the doors to PF-4 are open for less time during an evacuation, permitting less plutonium to escape in an accident. Third, change time-of-day assumptions in the model. Particles disperse less at night, when winds are calmer. More dispersion occurs in the day, reducing dose to an MEOI at any spot. Yet more plutonium is at risk during the day, when technicians are working with it; at night, it is stored in a less vulnerable state. At present, the model assumes daytime MAR and nighttime dispersion. Harmonizing MAR and time of day would reduce calculated dose.

Such changes in PF-4 accident modeling could reduce the calculated dose to the MEOI by several orders of magnitude. That reduction, if incorporated into PF-4's safety documents, would permit more than doubling the MAR permitted in PF-4. It would surely be faster and less costly to change the model and assumptions than to build a new plutonium building. At issue for Congress: would a change made to PF-4's MAR allowance by using the more realistic model increase risk to the public? If so, would the benefits obtained by using that model be worth the added risk?

Remove Contaminated Equipment

The Defense Nuclear Facilities Safety Board (DNFSB) monitors health and safety issues at DOE defense nuclear facilities. A DNFSB report of October 2014 stated in regard to PF-4, "an entire wall of legacy gloveboxes … contains degraded conditions that workers suspect has contributed to multiple contamination events during the past few years. LANL management does not currently have a plan to remove these gloveboxes in order to both eliminate the hazard and free up the considerable space for new programmatic work." Removing the gloveboxes would reduce the risk of a contamination accident, which would remove a room from service until the contamination was cleaned up, and would free up space. The gloveboxes will have to be removed eventually at the end of PF-4's life; there is a tradeoff between the advantages of removing them sooner and the drawback of incurring cost now rather than later.

Increase Material-At-Risk Ceilings by Using Conservative Rather Than Very Conservative Assumptions

DOE imposes a MAR limit specific to each building handling radioactive material so the dose to nearby workers and the public from an accident would not exceed limits specified by DOE. For a given MAR, dose is calculated with a ten-factor "MAR-to-dose" equation that includes the damage the building sustains, the fraction of plutonium released into the atmosphere by the event, and others. Five variables would vary from one scenario to another; NNSA typically assigns them a very conservative worst-case, or "bounding," value to keep dose within guidelines.

According to Kamiar Jamali, Associate Administrator for Safety and Health, Office of Nuclear Safety, NNSA, "Extreme conservatism is often intentionally exercised in safety analyses because it can pay dividends in simplified analysis and review efforts. However, the search for increased conservatism cannot be pursued without consequences. Extreme conservatism can lead to safety conclusions and decisions with significantly higher safety costs, which can make nuclear facilities, even those with very low hazard and risk profiles, prohibitively expensive." He proposed using the mean value for the variables "as the metric that is consistent with the concept of reasonable conservatism in nuclear safety analysis, as its value increases towards higher percentiles of the underlying distribution with increasing levels of uncertainty."[1] (For purposes of safety basis calculations applicable to LANL, mean and median are very close together.)

In the MAR-to-dose equation, using bounding values for a PF-4 accident calculation results in an estimated dose 35,000 times larger than when using median values. Yet an increase in the MAR ceiling in PF-4 by a factor of less than ten, and perhaps less than two, would probably permit enough MAR for production of 80 pits per year in PF-4. Increasing the MAR ceiling could also benefit AC. RLUOB is ideally configured for AC, but DOE regulations limit facilities like it to a level that, in the case of RLUOB, would be 26 g of weapons-grade plutonium, which has the volume of two nickels. Increasing the MAR ceiling by a factor of 40 or less might permit RLUOB to perform most of the AC needed to support production of 80 ppy. The most conservative assumptions provide the greatest margin of safety, but at the highest cost. At issue for Congress: at what point are the marginal costs no longer worth the marginal benefits?

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[1] Kamiar Jamali, "Achieving Reasonable Conservatism in Nuclear Safety Analyses," *National Nuclear Security Administration Technical Bulletin 2014-1,* July 2014, p. 2.

Use Additive Manufacturing to Make Tooling for Pit Work

Additive manufacturing (AM), often called 3-D printing, forms physical objects by depositing multiple layers of material. Many analysts view AM as the future of manufacturing. It can save time, space, and money; reduce waste; reduce the reject rate, increasing throughput; make parts on demand; and switch rapidly from making one part to making another. It can avoid some manufacturing steps, such as drilling holes, saving time and reducing the risk of error. It can make parts that are too complex to be manufactured in any other way. AM is not the best manufacturing method for all materials and components, and may not be suitable for some.

Recognizing the potential of AM, Congress, in P.L. 113-235, the Consolidated and Further Continuing Appropriations Act for FY2015, provided $12.6 million for AM for the nuclear weapons program, and the appropriations committees directed NNSA to provide "a ten-year strategic plan for using additive manufacturing to reduce costs at NNSA production facilities while meeting stringent qualification requirements." The report was due in mid-April 2015. In late April, NNSA indicated that it expects to transmit the report to Congress in several weeks.[2]

NNSA is exploring applications of AM in the nuclear weapons complex. Donald Cook, Deputy Administrator for Defense Programs at NNSA, said in January 2015, "within the last year, more than half of the new fixturing within the new Kansas City National Security Campus was made with AM processes."[3] (Fixtures hold material in place for machining and inspection.)

AM parts, such as tools and fixtures, might support pit production. In some cases, they can be stronger and lighter than conventionally made tools. They can be "lightweighted," e.g., made with honeycomb in areas that do not require much strength and solid in areas that do, providing ergonomic benefit for glovebox work. AM might save time, as it can prototype tools quickly and make them to order, increasing throughput. Currently, tools for pit work are made with conventional methods, which is generally satisfactory. However, "very little work is being done to explore tooling used in conjunction with pit production."[4] At issue for Congress: given the potential of AM, what applications, if any, might it have for pit production?

Use a Different Process to Fabricate Crucibles

The electrorefining process for purifying plutonium, discussed in "Discard Byproducts of Electrorefining," below, is conducted in magnesium oxide crucibles. A crucible consists of an outer cup, about 4.5 inches in diameter, and an inner cup. The process deposits a ring of purified plutonium in the space between the two cups. To fit in a furnace, this ring must be broken into several pieces so it can be melted for casting. This procedure has several problems. First, crucibles have been made as two separate cups, with the inner cup joined with an adhesive to the bottom of the outer cup. Sometimes, given the high heat and the reactive nature of plutonium, the adhesive fails and the cups come apart. Second, a failed electrorefining run produces more waste than a successful run, reducing throughput and increasing cost. Third, the plutonium ring is broken in a glovebox using a hydraulic breaking press; the breaking operation produces chunks, shards, and grains of plutonium metal. Shards may puncture gloves used in gloveboxes, posing a

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[2] Email, April 23, 2015.

[3] Email, January 12, 2015.

[4] Email, Lawrence Livermore National Laboratory, April 3, 2015.

risk to technicians. Fourth, this operation adds a process step and exposes workers to radiation. Fifth, the breaking press glovebox takes space that could be used to add an electrorefining station. So doing would increase the throughput of that process and support a higher pit production rate.

The United Kingdom's Atomic Weapons Establishment (AWE) is conducting final development trials of a crucible that addresses these problems. It is made in one piece with ridges running from the outer wall of the inner cup to the inner wall of the outer cup so that molten purified plutonium is deposited in segments, eliminating the need for a separate glovebox for breaking the plutonium ring and the resulting problems. These crucibles would appear applicable to U.S. electrorefining operations. On the other hand, development of the new crucibles is not complete, and there is no operational experience with them, so there is no guarantee that they will function properly in practice. A decision on whether to use them must therefore await additional data.

Options Involving Process Modifications

Develop and Qualify Accident-Resistant Containers

One way to reduce MAR in PF-4 is to place plutonium in containers designed to withstand a severe accident. If 10% of the plutonium in a container is expected to escape, as compared to all of that plutonium in a glovebox, MAR for that plutonium is reduced by 90%. "Damage ratio" measures the fraction of plutonium expected to escape: for a damage ratio of 1.0, all the plutonium is expected to escape; for a damage ratio of 0.1, one-tenth is expected to escape.

To reduce MAR, the reduction in damage ratio must be credited in PF-4's Documented Safety Analysis, which sets the limit on the amount of MAR allowed in PF-4. To qualify containers as having a certain damage ratio, they are subjected to intense testing. Technicians measure the amount of particulate that comes out of the container after each test. (Damage ratio does not apply to a complete collapse of PF-4, as containers are not expected to survive that event.)

Some years ago, Los Alamos used a container that had a damage ratio of 0.05. Since then, a newer container has been introduced commercially, with a damage ratio of 0.01. These containers are intended for long-term storage, not for ease of use in gloveboxes. Yet a substantial amount of plutonium on PF-4's lab space is in process. Placing more of that plutonium in containers when not in immediate use would reduce MAR on the main floor. At issue: would this use of containers adversely affect plutonium processing?

Process Plutonium Samples More Efficiently

Pit production requires a detailed characterization of plutonium at various stages, from the electrorefined product to hemishells to waste streams, to determine if the sample falls within required specifications. This characterization is done with analytical chemistry (AC). Samples of metal for AC are taken from larger pieces of plutonium and dissolved in acid. The liquid is split into smaller samples for analysis. Many contain milligram or smaller quantities of plutonium.

At present, LANL conducts most plutonium AC in the Chemistry and Metallurgy Research (CMR) building. CMR opened in 1952 and is in poor condition. NNSA plans to halt programmatic activities there by FY2019. As part of that plan, NNSA plans to move most AC to RLUOB. However, it is not known if RLUOB has enough space and a high enough MAR limit to conduct, along with PF-4, the AC needed to support production of 80 ppy. One way to reduce space and MAR required for AC is to analyze fewer samples per pit. That would enable fewer pieces of equipment to support a given rate of production, reducing space requirements and cost and increasing throughput; would make it more likely that RLUOB could perform most AC needed, which would reduce the amount of AC that would have to be done in PF-4; and would reduce waste generated per pit, reducing the load on AC and on waste processing. Similarly, smaller samples, or samples measured with less accuracy for some processes, might suffice.

The chief concern about taking fewer or smaller samples per pit or performing fewer or less accurate analyses is a reduction in precision. This concern can be addressed in several ways. For some process steps, less accurate analytic techniques would suffice; using them may increase throughput. As pit production rate increased, fewer samples per pit taken during metal production would probably suffice to demonstrate that production processes were operating properly. The experience level of technicians would be expected to increase as production rate increased, reducing the need for rework and increase throughput of sample analysis.

Discard Byproducts of Electrorefining

Plutonium must be purified to be used in pits. This process involves several steps; the final step is electrorefining. In electrorefining, an ingot of impure plutonium is placed in the inner cup of a crucible. The rest of both cups are filled with a salt mixture that acts as an electrolyte. Plutonium and salt are melted at high temperature, and an electric current is passed through the mixture. The process produces a ring of purified plutonium and two byproducts, an ingot of impure plutonium (the “heel”) in the inner cup, and the salt, which retains some plutonium (here referred to as the Pu-salt mixture). The plutonium in the heel is converted to plutonium oxide; it and the Pu-salt mixture are dissolved (separately) in acid to recover their plutonium.

PF-4 has two “aqueous” process lines, i.e., those that involve a liquid. One uses hydrochloric acid and the other uses nitric acid. They dissolve plutonium compounds in acid. Recovering plutonium from the liquid involves extensive MAR, space, and labor. Might it be possible to reduce this burden? Data from 653 electrorefining runs at LANL, 1964-1977, are available. While the data are old, the process for electrorefining plutonium has not changed much since that time, so the figures provide a rough idea of the products of electrorefining: 9.2% of the plutonium left in the heel; 10.7% left in the salt and stuck to the crucible, almost all of which is in the salt; 78.8% purified in the product ring; and a small amount elsewhere.

Might it be possible to discard the Pu-salt mixture and the heel? That would lose some plutonium, but would avoid the need to use aqueous processes to recover it. The plutonium loss would arguably not be a problem. The U.S. plutonium inventory was 95.4 metric tons as of September 2009, with 43.4 metric tons surplus to defense needs;[5] pits use kilogram quantities of plutonium. The Pu-salt mixture could probably be sent to the Waste Isolation Pilot Plant (WIPP), the nation’s underground storage repository for such waste, once it reopens. The heel could be converted to plutonium oxide for shipment. Shipping the material to WIPP would avoid the need to send it through aqueous processes, reducing the space and MAR needed for these processes or permitting existing equipment to process more plutonium in order to support a higher rate of pit production. Congress may wish to consider the costs vs. benefits of discarding this plutonium.

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[5] U.S. Department of Energy, *The United States Plutonium Balance, 1944-2009*, Washington, DC, June 2012, p. 2, http://nnsa.energy.gov/sites/default/files/nnsa/06-12-inlinefiles/PU%20Report%20Revised%2006-26-2012%20%28UNC%29.pdf. One metric ton is 1,000 kilograms, or 2,205 pounds.

Use Calcium Chloride for Electrorefining

Electrorefining uses sodium chloride and potassium chloride. That entails several problems. Plutonium held in salts reduces yield (fraction of total plutonium recovered as pure plutonium), increasing time, space, equipment, MAR, cost, process steps, and worker exposure required to produce a given amount of pure plutonium. Hydrochloric acid processing for recovering plutonium produces a substantial waste stream that requires further treatment. The plutonium content of this waste must be monitored with AC techniques, adding to the workload. Preparing plutonium-contaminated waste for disposition takes up space in PF-4 and elsewhere at LANL. The process from waste generation to processing to disposition is costly.

An alternative would be to use calcium chloride as the electrolyte. Lawrence Livermore National Laboratory (LLNL) has used this method since 1992 and AWE has used it for over a decade. This approach offers several advantages. Calcium chloride retains less plutonium after an electrorefining run, increasing the yield. A process ("salt scrub") can remove most of the rest of the plutonium from the calcium chloride-plutonium mixture. As a result, the salt left after the salt scrub would be expected to contain very little plutonium. Disposing of that salt as waste would release aqueous process capacity. In this way, equipment could produce more plutonium, supporting a higher rate of pit production.

LANL had poor results when it tried this approach in the 1990s. It plans to revisit this option. LANL will use sodium chloride and potassium chloride when electrorefining in PF-4 resumes, but plans to convert to calcium chloride if the process can be successfully demonstrated. LANL expects to draw on LLNL and AWE resources and experience in this effort.

Remove Americium from Plutonium

Weapons-grade plutonium (WGPu) consists of several plutonium isotopes. Each decays radioactively at its own rate. Pu-241 decays much faster than the others, producing americium-241 (Am-241). It is desirable to remove Am-241 because it is an intense emitter of low-energy gamma rays. While these gamma rays are relatively easy to shield, so that gloveboxes protect workers' bodies from them, workers handling aged WGPu in gloveboxes have only gloves to protect their hands. As a result, gamma rays from Am-241 can provide substantial dose to their hands. This dose can be the limiting factor in how many days per year federal regulations and LANL policies permit them to handle plutonium while staying within dose guidelines. Am-241 can be removed through a process, metal chlorination, that captures almost all the americium.

Of the Pu-241 in newly produced WGPu, 89% will have decayed to Am-241 after 50 years. Most U.S. WGPu was produced between 1956 and 1970. It had essentially no impurities resulting from radioactive decay when newly produced; plutonium purified since then has, in effect, had its age reset to zero. There is no official unclassified (and perhaps no classified) figure for the average age of plutonium in the DOE inventory, but preliminary calculations by LANL are that the average age of that plutonium is about 50 years. Due to radioactive decay, little Pu-241 is left to form more Am-241 after 50 years. Since Pu-241 decay is the only source of Am-241, after passing aged plutonium through a final run of metal chlorination to remove Am-241, so little Pu-241 would remain that even if it all decayed to Am-241, the latter would never reach the level in 30-year-old WGPu, and the weapons laboratories have certified weapons with pits that old and older as acceptable for use in the stockpile. This final run would greatly reduce worker exposure. Also, since additional runs of metal chlorination would not be needed for WGPu thus processed, capacity of the metal chlorination line could be reduced, reducing space and operating cost.

Accept More Uranium in Weapons-Grade Plutonium

Pu-241 decays faster than the other plutonium isotopes in WGPu. The others decay over longer times into uranium. After 50 years, uranium accounts for 0.17% of WGPu, and uranium will form at this rate, declining only slightly, for millennia.

At issue is whether newly fabricated pits can use plutonium that has not been purified for several decades, or if the uranium would affect pit performance. The last year in which the United States made pits for the stockpile (with a minor exception) was 1989. NNSA plans a life extension program (LEP) for the B61 bomb, with the first production unit expected in FY2020. Thus the newest pit in B61s would, in 2020, be at least 30 years old. Yet the LEP is to use existing pits, and weapon designers expect to be able to certify the performance of life-extended B61 bombs. Similarly, the W76 warhead was first manufactured in 1978 and is now undergoing an LEP that does not use new pits. A 2007 report by the JASON group evaluated studies on pit lifetime performed by LANL and LLNL, and found "no evidence from the [underground nuclear testing] analyses for plutonium aging mechanisms affecting primary performance on timescales of a century or less in ways that would be detrimental to the enduring stockpile."[6] Thus there may not be a need to conduct electrorefining to purify plutonium for pits for decades. Capacity and space required for pit production could be further reduced if weapon designers were willing to allow a larger uranium content in the WGPu specification. That would depend on detailed studies of properties of WGPu with levels of uranium isotopes that are in existing pits.

Use Near Net Shape Casting to Fabricate Hemishells

Hemishells are cast by gravity feed, i.e., pouring molten plutonium between an inner and outer mold. When it solidifies, the molds are separated and the cast part is removed. The part is heat-treated to impart the required material properties. It is then machined to final dimension. Near net shape casting (NNSC) has a thinner space between the molds, yielding a cast part much closer to final dimension. Otherwise, processing is the same. The thinner space requires less plutonium for casting, reducing the amount of plutonium that must be machined away to produce the hemishell. On the other hand, a thinner cast part could result in a higher reject rate, as there would be less margin for error in machining. To offset this disadvantage, NNSC could use various electronic techniques to align the part more precisely and remove excess material more precisely.

Current equipment can purify enough plutonium to support low production rates, but supply would become a bottleneck at higher pit production rates. Since NNSC uses less plutonium per hemishell, existing equipment could provide plutonium for a higher rate of pit production. Using less plutonium per pit would reduce the waste stream, the burden on material control and accountability, and, on a per-pit basis, worker exposure, MAR, and cost. LANL has conducted some R&D into NNSC using gravity feed and plans to use this method in the future if it proves successful. LANL's planning basis for future pit manufacture includes it. LLNL worked on developing NNSC as early as 1994, and has demonstrated NNSC using plutonium die casting, in which molten plutonium is forced into the space between an inner and outer mold. LLNL stated in April 2015, "Die casting technology is another approach to significantly reduce the amount of plutonium required per casting and therefore, the amount of feed metal."

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[6] R.J. Hemley et al., "Pit Lifetime," JASON, The MITRE Corporation, JSR-06-335, January 11, 2007, p. 1, http://fas.org/irp/agency/dod/jason/pit.pdf. A nuclear weapon's primary stage consists of the pit, high explosives, and other components.

Options Involving Structural Modifications to PF-4

Augment Seismic Resilience of PF-4

PF-4 became operational in 1978; since then, seismic studies have increased the predicted threat to it. For example, an older model assumed that an earthquake would shake the building, while a newer model treated an earthquake as a wave of earth that could push PF-4 over. These studies increased concern that a major earthquake could collapse PF-4. In 2013, to reduce the dose resulting from collapse followed by a fire, LANL reduced PF-4's MAR limit for the main (laboratory) floor from 2,600 kg PE to 1,800 kg PE. To increase MAR, reduce potential dose, and reduce the risk of collapse, LANL is taking steps to strengthen PF-4 seismically.

To strengthen PF-4 against seismic shaking, LANL added a drag strut to the roof. (A drag strut gathers lateral forces from a large flat surface and transmits them to a shear wall, which is designed to resist those forces.) Other steps strengthened PF-4 against pushover. Many columns that run from the basement to the roof support PF-4. Some run through a plutonium vault in the basement. Its ceiling holds them rigidly in place, making them more vulnerable to shear forces that could collapse them. Collapse could result in concrete and steel crashing through the vault ceiling. To strengthen the columns, LANL wrapped them in carbon fiber sealed with epoxy. LANL is now working to strengthen the ties between girders, which are located above the laboratory floor of PF-4, and other structural elements. To reduce the risk of fire, LANL removed about 20 tons of combustible material from PF-4, mostly from the lab floor, and plans to upgrade the system that would deliver water to PF-4 and nearby buildings for firefighting. Such upgrades could greatly reduce the amount of plutonium released in an earthquake and fire. The Consolidated and Further Continuing Appropriations Act, 2015, P.L. 113-235, provided $1 million for seismic safety mitigation for PF-4 and nearby facilities.

Build One Module for Plutonium-238 Work

Plutonium-238 (Pu-238) is highly radioactive. It is used in deep space probes and has some military applications. It is not used in pits. As of February 2013, PF-4 held about 1.6 kg of Pu-238, but because of its high radioactivity it accounted for 24.5% of the building's MAR. For comparison, pit fabrication accounted for 26.4% of the building's MAR. In addition, Pu-238 programs accounted for 9,600 square feet, or 16%, of PF-4 laboratory floor space.

One approach to providing more MAR and space in PF-4 for pit fabrication is to build modules, buried reinforced-concrete structures with about 5,000 square feet of lab space connected to PF-4 by tunnels. As stated in the FY2016 DOE budget request, "NNSA is planning to construct not less than two modular structures that will achieve full operating capability not later than 2027." However, Pu-238 is not uniformly distributed within the space for Pu-238 programs. If some Pu-238 work were moved to a module, that module could accommodate most of the Pu-238-related MAR from PF-4, releasing MAR and space for pit production or other plutonium work. Thus one module for Pu-238 might suffice to enable pit production in PF-4.

Building one module may offer advantages if others are to be built. Modules would have a basic design, and each would be provided the capabilities needed for its specific mission. In contrast, a large multi-mission building would require all features needed for every mission it contained. Building a module would provide lessons that could reduce cost of other modules. NNSA states that modules offer "the potential to scale facility acquisition to appropriations and adapt more quickly to changes in program requirements." On the other hand, some lessons from building a module might increase cost. A design flaw or a need for larger modules or more concrete could make the second module more expensive than the first. Also at issue is whether other measures to increase MAR and space margin might provide enough margin without any modules.

Conclusion: Choosing a Package of Options

This report shows options, many of which NNSA and its labs are pursuing, that can help move toward the ability to manufacture pits at a rate of 80 per year by 2027. One option by itself will not suffice to meet that requirement. As a result, NNSA faces the prospect of assembling a package of options, and Congress faces the prospect of evaluating, perhaps amending, and approving it. Any package would need to optimize among such goals as margin, cost, worker safety, and throughput. Questions and tradeoffs to consider in formulating a package include:

- MAR reduction techniques include strengthening PF-4, using special containers for plutonium not in use, and removing contaminated gloveboxes. Would all such techniques be needed, or would some provide enough MAR margin?
- Using a different wind model and more realistic assumptions could reduce calculated dose by more than half in a major accident at PF-4, permitting more than doubling the MAR allowance for PF-4 quickly and at essentially no cost. Would that suffice?
- Techniques to increase space margin include removing contaminated gloveboxes, setting up a production line able to make 50 ppy with one shift per day and operating it with two shifts per day, and building a module for Pu-238 work. Which combination of techniques would be most cost-effective?
- A module for Pu-238 work would permit moving much MAR out of PF-4 and freeing some space there. Would that module be cost-effective, or would other alternatives render it unnecessary? Would other advantages argue for building a Pu-238 module even if enough margin could be obtained by other means?
- Using conservative rather than very conservative assumptions to calculate dose could reduce the need for costly, time-consuming changes to PF-4. Would that increase risk to workers and the public substantially? What is the risk-benefit balance?

In sum, while arriving at a satisfactory package will require complex analyses, many options offer the potential to boost U.S. pit production capacity toward, if not to, the congressionally mandated requirement of 80 pits per year by 2027.

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