

Dilute and Dispose: The Best Approach for Surplus Plutonium Disposition

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Disposal of Surplus Plutonium in the Waste Isolation Pilot Plant

Presentation to the Committee
National Academies of Science
Washington, DC, November 29, 2017

UCS position on surplus plutonium disposition

- Retrievable storage of surplus plutonium in highly attractive and readily reusable forms is not an acceptable long-term strategy
- However, the “cure” should not be worse than the “disease:” plutonium disposition activities should not cause an unacceptable life-cycle increase in security, safety or environmental risks
 - In our analysis, reactor options, including MOX in light-water reactors, do not meet this standard
 - Non-reactor, direct disposal options, including dilute and dispose (D&D), can meet this test, provided that outstanding safety, security and environmental concerns are adequately addressed
 - Risks associated with any approach must be evaluated in the context of the default option (indefinite storage of separated Pu)
- A coordinated and sustained effort by responsible parties within and without DOE will be necessary in order to effectively implement D&D for the entire surplus plutonium inventory
 - In particular, front-end and back-end must be addressed together

Scope of problem

- Disposition of 34 metric tons of surplus weapons-grade plutonium in the U.S. as MOX fuel in LWRs governed by the 2000 Plutonium Management and Disposition Agreement (PMDA) amended by 2010 Protocol (SOT 1)
 - 25.6 MT clean pit and non-pit metal and oxide
 - 8.4 MT impure metal and oxide
- Disposition of at least an additional 13 metric tons of surplus pit and non-pit plutonium, including non-weapons-grade material and plutonium contained in Japan's Fast Critical Assembly (SOT 2c)
 - 6 MT owned by EM; 7 MT owned by NNSA
- A comprehensive plan should address both categories

Fundamental drivers of surplus Pu disposition

- Domestic security
 - Reduce vulnerability to subnational theft
 - Reduce associated security costs
 - Shrink footprint or eliminate Category I/II facilities
 - Reduce future uncertainty
- Domestic safety
 - Reduce interim storage risks
 - Ensure stable long-term disposal strategy
- Bilateral and international security
 - Fulfill commitment to arms reductions
 - Set example for other countries with surplus Pu
 - Encourage reversal of PMDA suspension by Russia
 - Demonstrate an effective approach for bilateral/international monitoring and verification of Pu disposal
- Committee's assessment of the “general viability” of WIPP disposal should include consideration of security and verification

Russia and PMDA commitments

- “What did Russia do? We developed this fuel, built a plant for mass production and, as we pledged in the agreement, built a BN-800 plant that allowed us to safely burn this fuel. I would like to emphasize that Russia fulfilled all of its commitments.”
 - Russian President Vladimir Putin, Valdai Club speech, 19 October 2017
- Current operation of BN-800 not consistent with PMDA commitments
 - First core 100% HEU? (due to MOX fabrication delays)
 - Second core 16% MOX (reactor-grade)
 - Plan to increase MOX to 100% by 2019; “no plans” to use weapons-grade MOX
 - Utility of current MOX fuel fabrication lines for WG-Pu is unclear
 - Breeding ratio > 1



**BN-800, Beloyarsk, Russian Federation, June 2017
(courtesy: E. Lyman)**

Spent fuel standard

- The NAS introduced the “spent fuel standard” (SFS) concept in 1994 as an appropriate endpoint for surplus Pu disposition
 - “roughly as inaccessible for weapons use as the much larger and growing stock of plutonium in civilian spent fuel”
 - intrinsic properties only
- Intended to address the risks of host state recovery and terrorist theft
- Chief attributes:
 - Mass and bulk of disposition item
 - Plutonium dilution
 - “Self-protecting” radiation barrier (Cs-137)
- The NAS appropriately ranked plutonium isotopic composition (WG versus RG) as a far less important factor; allowed consideration of direct disposal of WG-Pu (e.g. immobilization with HLW)
- Spent LWR MOX fuel and immobilization* were judged to meet the SFS
 - * Homogeneous immobilization only; NAS withheld judgment on can-in-canister immobilization

Role of the radiation barrier

- The NAS judged that chemical dilution without a radiation barrier was insufficient to meet the SFS
 - Experienced chemists can recover plutonium from any form given sufficient time and resources
 - Radiation barrier should inhibit theft and preclude chemical processing in gloveboxes
- However, this assumed that most spent fuel would be emplaced in a geologic repository before ceasing to be self-protecting, which may no longer be likely
 - The benefit of providing a substantial radiation barrier may not justify the cost if a significant inventory of low radiation barrier spent fuel remains in surface storage
- In any event, the current self-protection standard (> 100 rem/hr at 1 meter) is not longer considered an adequate deterrent

Role of Pu isotopics

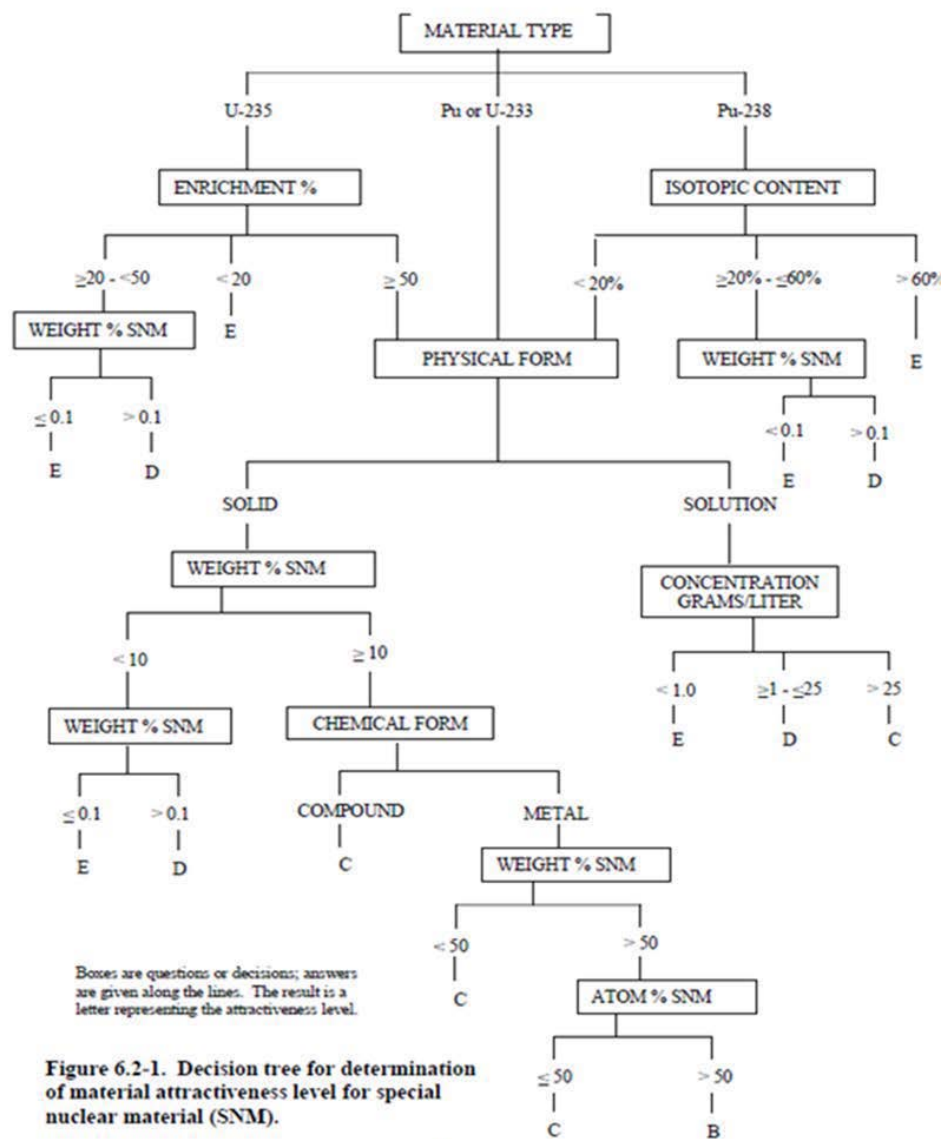
- Initially, DOE pursued a two-track disposition program
 - MOX for clean Pu and immobilization with HLW for impure Pu
 - Russia gave consent
- DOE released a declassified statement confirming the weapon-usability of reactor-grade plutonium for both states and terrorists
- In 2002 DOE cancelled immobilization in favor of MOX
 - Although immobilization was the lower-cost option, DOE asserted that Russia would never accept only immobilization because it did not change the isotopic composition and hence was not irreversible
- This decision caused additional difficulties and delays
 - Required MOX plant redesign to enable more complex processing
 - Stranded a significant amount of plutonium without a disposition path

Dilute and Dispose (D&D)

- A disposition method that balances the reduction of plutonium attractiveness and accessibility with cost and timeliness considerations
- Already demonstrated for a substantial quantity of plutonium
- A straightforward, relatively simple, dry, room-temperature process (mechanical mixing of powders)
- Dilute and Dispose (D&D) baseline approach
 - Dilution (< 10 weight-percent Pu)
 - Pu limit per item (< 380 g for Criticality Control Overpack)
 - Chemical inhibitor of dissolution/separation (“stardust”)
 - Timely emplacement in geologic repository (WIPP)
- Does not meet the SFS because of the lack of self-protection, but may provide a sufficient barrier to rapid recovery of a weapon-relevant quantity of Pu

Termination of domestic safeguards

- Safeguards termination required on items shipped to WIPP
 - WIPP is currently a “property protection area”
- Generally requires Attractiveness Level E designation
 - solid with < 0.1 wt-% Pu or “highly irradiated” (unquantified)
- DOE allows termination of safeguards on Attractiveness Level D items if security analysis shows no significant risk increase
- DOE terminated safeguards on D&D items by diluting or blending plutonium to below 10 wt-%, restricting loading to 200 g Pu and conducting a vulnerability assessment
- Security classification of D&D items may have recently changed



"Stardust"

- Some highly attractive Pu residues required use of a special diluent called termination of safeguards (TOS) material (or "stardust") in order to reduce attractiveness level to D
 - "A mixture of cementing, gelling, thickening and foaming agents" to make it "more difficult and complex to recover, concentrate and purify the plutonium"
 - "Stardust" compositions are marked "unclassified controlled nuclear information (UCNI)"
- Said to increase delay in recovery of a weapons-relevant quantity of Pu by an adversary
- Does not provide a meaningful barrier to host state re-use in principle, but perhaps does in practice:
 - "...based on the premise that attractiveness of SNM-bearing materials must be directly related to difficulty of recovery and the assumptions that DOE does not have infinite resources to apply to recovery..." – LANL, 1996

D&D vs. SFS

- Presumably, past security assessments have determined that the additional time and resources needed to recover a Category II quantity of Pu from D&D waste forms were sufficient to justify terminating domestic safeguards
 - Considerable credit given to the properties of “stardust”
 - Determinations may have been driven more by programmatic needs than robust technical analysis
- Individual items are easier to steal than SFS waste forms, but many more are needed (300 g Pu/item compared to 11000 g Pu/item)
- This may support a conclusion that D&D can be regarded as an alternate but comparable measure to the SFS
- In either end state, plutonium is not “practicably irrecoverable” and any IAEA verification would likely need to extend to the final repository

	D&D	MOX spent fuel (Westinghouse PWR)
Radiation barrier	No	Yes
Pu concentration (wt-%) in “not readily separable” matrix	< 10%	2.5%
Pu quantity/item (g)	300	12,000
Item weight (kg)	160	450

Geologic versus intrinsic barriers

- The SFS was rooted in an assumption that Pu disposition waste forms would be in the same boat with civilian spent fuel with regard to final geologic disposal (e.g. Yucca Mountain)
- However, D&D provides a path for sending plutonium to geologic disposal far sooner than hot, highly radioactive waste forms that must await a spent fuel repository
- The geologic barrier is formidable and compensates for lack of a radiation barrier
- Radiation barrier will decline over time for SFS disposition forms and spent fuel, increasing vulnerability in interim surface storage

Verification issues

- The D&D process should be easier for the IAEA to monitor/verify than the MOX process
 - Dilution is accomplished within a single glovebox: compare to complexity of MOX program
- International monitoring of an underground repository is easier than monitoring multiple surface storage sites
 - Containment and surveillance at WIPP should be straightforward
- Caveats:
 - Stardust compositions are UCNl
 - Although this is not likely to present a problem for IAEA verification, approaches for termination of safeguards without the use of “stardust” would be preferable to allow increased transparency

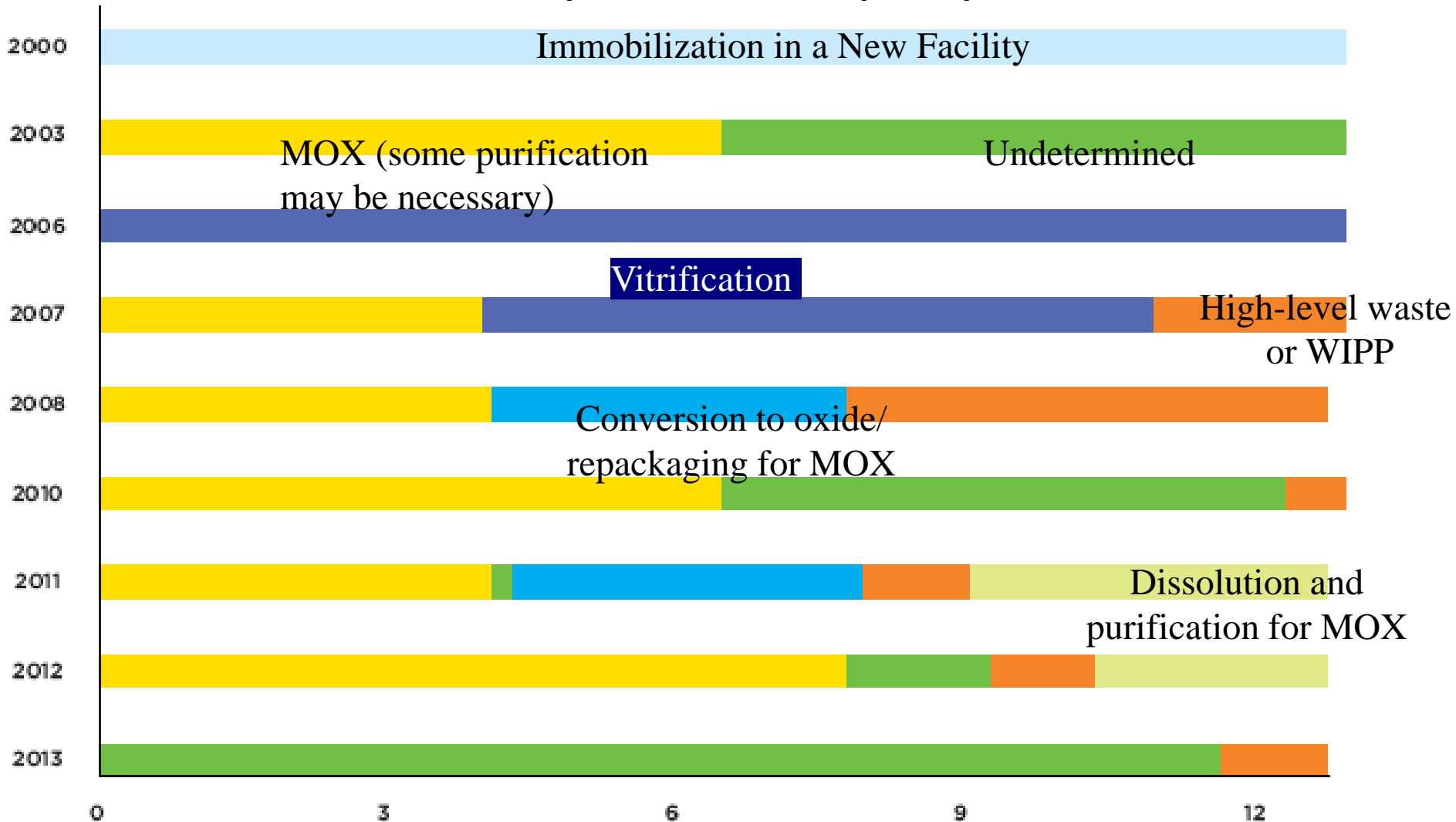


K-Area glovebox for D&D operations (from K. Fuller, Savannah River Nuclear Solutions, "Savannah River Downblending Program for Surplus, Non-Pit Plutonium, Institute of Nuclear Materials Management Annual Meeting, Atlanta, GA, July 2016

Assessing the “general viability” of D&D

- Feasibility of necessary facility modifications/repurposing/new construction
 - Feedstock preparation (oxide conversion of pits/metals)
 - Expanded capacity for dilution operations at SRS
- Ensuring adequate lag storage of D&D waste drums
- Implementing approaches to resolve **upfront** any technical, legal and regulatory issues that may constrain timely emplacement of the **entire** surplus Pu inventory in WIPP
 - Physical expansion
 - Statutory limit on TRU waste volume
 - Safety, environmental and security impacts
- Ensuring adequate capacity, safety and security for all necessary transport links
- Ensuring effective long-term project management and funding
- Ensuring that domestic security objectives are met and that the entire process can be effectively monitored/verified

Changing disposition strategy for 13 MT of impure non-pit plutonium



Assessment of infrastructure needs

- Pit disassembly and metal oxidation
 - Choice of method
 - LANL and/or SRS? Elsewhere?
 - Existing facilities (PF-4, K-Area Complex), portion of MFFF building, or new buildings?
- Dilution and packaging
 - KAC only? MFFF? Waste Solidification Building (WSB)? Elsewhere?
- Interim storage
- Transportation infrastructure
- Throughput goal: > 1.5 MT Pu/year
 - Safety and security upgrades, hiring/training personnel

The back-end

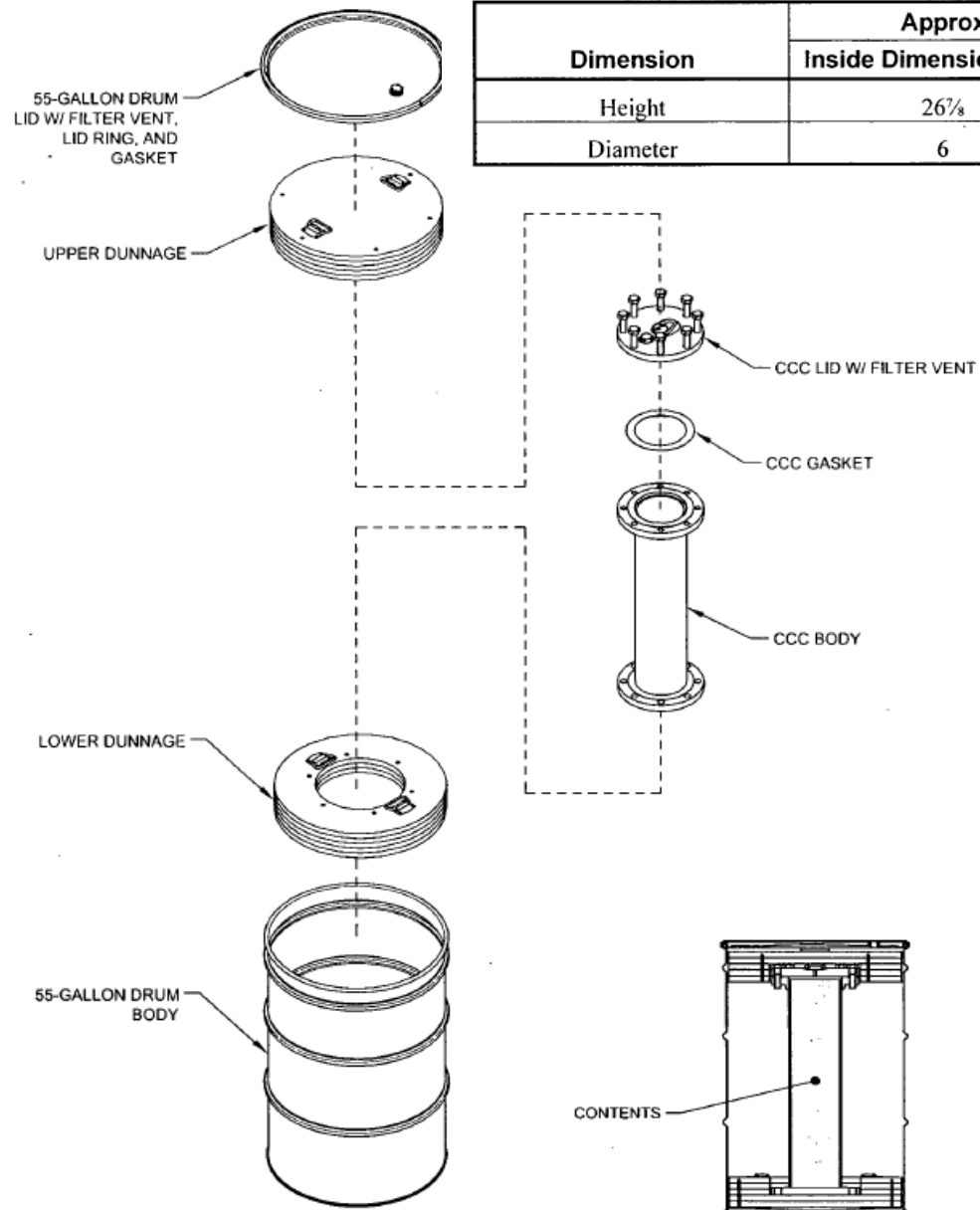
- Limit on WIPP statutory capacity
 - Many competing demands for remaining space (some with more merit than others)
 - D&D should be given priority over other potential waste streams that do not meet WIPP criteria
- Limit on WIPP physical capacity
 - Prematurely closed panels
 - Unstable panels
- Increased plutonium source term
 - Only a concern for human intrusion scenarios and criticality evaluations

Options for addressing statutory volume limit

- Amend 1992 Land Withdrawal Act (likely non-starter)
- Site and build new repository (definite non-starter)
- Redefine TRU waste volume (largely political)
 - D&D waste forms (factor of 15-600 reduction)
 - Recapture empty volume in drums already emplaced
- Increase Pu loading per waste drum
 - Tradeoffs include impacts on security and repository performance

Table 2.9-42 – CCO Dimensions

Dimension	Approximate Measurement (inches)	
	Inside Dimension (CCC)	Outside Dimension (drum)
Height	26 $\frac{7}{8}$	35
Diameter	6	24



Alternatives to D&D baseline

- Terminating safeguards on fairly rich materials (10% Pu) with credit for “stardust” may be hard to justify for a large surplus Pu disposition campaign
- Alternatives exist for further reducing accessibility of Pu in D&D items, but may increase cost, time and risk
 - Dilution below 1% in cement grout
 - Immobilization in highly refractory materials
 - Multiple, randomly assigned “stardust” compositions
- Cementation option at WSB could increase plutonium loading by up to a factor of 10 per item, but would have impact on criticality, security risks and environmental risks, as well as weight limits
 - Approach warrants further evaluation
 - 1 kg/item loading at 0.3 wt-% Pu
- A study of alternatives is being conducted by NNSA

Table 6.2-3. Additional Attractiveness Level E Criteria for SNM

Description/Form		
	Maximum SNM concentration* (wt%) for MC&A and physical protection termination	Maximum SNM concentration* (wt%) for only physical protection equivalent to Category IV
SNM solutions and oxides: nitrate, caustic or chloride solutions, contaminated/impure oxides, metal fines and turnings, glove box sweepings	0.1	N/A
SNM amenable to dissolution and subsequent separation: pyrochemical salts, chloride melt, hydroxide cake, floor sweepings, alumina, condensates reduction residues, sand, slag, and crucible, magnesium oxide crucibles spent fuel and spent fuel residues	0.1	0.2
SNM in organic matrixes or requiring mechanical separation disassembly and subsequent multiple recovery operations: HEPA filters, organic solutions, oils and sludges, graphite or carbon scrap, surface contaminated plastics, metal components, combustible rubber	0.2	1.0
SNM bound in matrix of solid, sintered, or agglomerated refractory materials: SNM embedded in glass or plastic, high-fired incinerator ash, spent resins, salt sludges, raffinates, and sulfides	0.5	2.0
SNM microencapsulated in refractory compounds or in solid-dilution: vitrified, bituminized, cemented, or polymer-encapsulated materials, SNM alloyed with refractory elements (tungsten, platinum, chromium, stainless steel); ceramic/glass salvage	1.0	5.0

Plutonium isotopics

- The hope that Russia would change its original position and accept a U.S. disposition option that does not alter Pu isotopic composition was dashed in April 2016, when Russian president Putin and Rosatom representatives publicly criticized D&D:
 - *The only way to irreversibly turn plutonium into a material not usable in a nuclear weapon is by changing its isotope composition. Any chemical method is reversible,”* Rosatom spokesman Vladimir Troyanov
- However, if Russia insists on isotopic dilution to > 10 percent Pu-240, the U.S. could in principle import 20 MT of Japanese or British plutonium stored in Europe for blending
 - Could the U.S. D&D system handle the larger quantity of plutonium?
 - Higher radiation and heat levels of RG-Pu may complicate glovebox processing

Conclusions

- Security and safety concerns associated with D&D should be considered in relation to those of the alternative: indefinite surface storage of separated plutonium
- A multi-agency steering committee is needed to coordinate all the parties and moving parts
- NAS study should include consideration of material attractiveness and ease of international verification

Acronyms

- D&D: Dilute and Dispose
- KAC: K-Area Complex
- MFFF: Mixed-Oxide Fuel Fabrication Facility
- PMDA: Plutonium Management and Disposition Agreement
- RG-Pu: Reactor-Grade Plutonium
- SFS: Spent Fuel Standard
- SOT: Statement of Task
- TOS: Termination of Safeguards
- WG-Pu: Weapons-Grade Plutonium
- WSB: Waste Solidification Building