Terminating Safeguards on Excess Special Nuclear Material: Defense TRU Waste Clean-up and Nonproliferation - 12426

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ABSTRACT

The Department of Energy (DOE) and the National Nuclear Security Administration (NNSA) manages defense nuclear material that has been determined to be excess to programmatic needs and declared waste. When these wastes contain plutonium, they almost always meet the definition of defense transuranic (TRU) waste and are thus eligible for disposal at the Waste Isolation Pilot Plant (WIPP). The DOE operates the WIPP in a manner that physical protections for attractiveness level D or higher special nuclear material (SNM) are not the normal operating condition. Therefore, there is currently a requirement to terminate safeguards before disposal of these wastes at the WIPP. Presented are the processes used to terminate safeguards, lessons learned during the termination process, and how these approaches might be useful for future defense TRU waste needing safeguards termination prior to shipment and disposal at the WIPP. Also described is a new criticality control container, which will increase the amount of fissile material that can be loaded per container, and how it will save significant taxpayer dollars.

INTRODUCTION

During the height of the Cold War, the United States arsenal of nuclear weapons served as a deterrent to attack. The Cold War nuclear arsenal contained a large quantity and variety of nuclear weapons. This insured the flexibility and reliability of the deterrent force. The Cold War ended, and over time, the strategic mission for nuclear weapons and the nuclear weapons complex has changed. The nuclear weapons complex must still provide the United States with a safe, secure, and effective nuclear deterrent, but with smaller numbers of weapons. Hand in hand with this mission is the safe and secure dismantlement of weapons no longer needed in the nuclear arsenal and the transformation of the Cold War nuclear weapons complex from one based on quantity, variety, and frequent replacement to refurbishment, reuse, and science-based life extension. The vision for a new nuclear weapons complex is for a smaller and less expensive infrastructure with fewer facilities and fewer storage areas for special nuclear material (SNM) [1].

SNM is simply Pu, U-233, or uranium enriched in U-235 [2]. In other words, SNM is fissionable materials that could be used to manufacture nuclear weapons. With a smaller complex, fewer storage facilities, and treaty obligations reducing the nuclear arsenal, SNM is sometimes withdrawn from use in weapons or weapon-related activities and is no longer needed to support current or future national security requirements. The Department of Energy (DOE) and the National Nuclear Security Administration (NNSA) manage these materials as excess. If these excess fissile materials are also declared to be of no DOE or NNSA programmatic use, then they must be made “non-weapons-usable” in support of U.S. non-proliferation goals [3]. This can be done by consuming the material in a DOE or non-DOE program, conversion to a difficult to recover material and storage, or disposal as waste.

Historically, DOE and NNSA have chosen to dispose of some of the nuclear materials that were determined excess and of no programmatic use. When these materials contained plutonium, they almost always met the definition of defense transuranic (TRU) and, if declared waste, would thus meet key requirements for disposal at the Waste Isolation Pilot Plant (WIPP). However, the form and amount of SNM in the original materials sometimes required safeguards per DOE order. The DOE has always operated the WIPP in a manner that the level of safeguards these materials required was not the normal operating condition. Therefore, it became necessary to terminate safeguards on the material before declaring it waste and shipping it to the WIPP for disposal.

From this experience, there exist a number of examples, from a variety of DOE sites, where successful termination of safeguards was done and the defense TRU waste was disposed of at the WIPP. Based on a new vision for a smaller DOE complex with fewer storage areas for SNM, there might be more materials declared excess with no programmatic use that are considered for disposal in the future. The processes that have been used to successfully terminate safeguards in the past might be useful for future defense materials needing safeguards termination in order to be shipped to the WIPP for disposal.

BASIS OF GRADED SAFEGUARDS

“Graded safeguards” is the term used to describe a system of varying degrees of physical protection, accountability, and material control that is applied to different types, quantities, physical forms, and chemical or isotopic compositions of nuclear material. The graded-safeguards concept is used to provide the greatest amount of control and accountability for SNM that can be most effectively used in a nuclear explosive device or for other nuclear materials that have high strategic and monetary value [2]. The system is based on two variables for the material, its attractiveness and the amount of material present. These two variables determine the category of the material and, therefore, the level of graded safeguards required. DOE O 474.2, Change 1, *Nuclear Material Control and Accountability*, 8-3-11, contains the graded safeguards table for Pu, U-233, U-235, separated Np-237, separated Am-241 and separated Am-243. Table I is the Pu/U-233 portion of the graded safeguards table from that order.

Table I. Graded Safeguards Table.

	Attractiveness Level	Pu/U-233 Category (kg)			
		I	II	III	IV[1]
WEAPONS Assembled weapons and test devices	A	All	N/A	N/A	N/A
PURE PRODUCTS Pits, major components, button ingots, recastable metal, directly convertible materials	B	≥2	≥0.4<2	≥0.2<0.4	<0.2
HIGH-GRADE MATERIALS Carbides, oxides, nitrates, solutions (≥25g/L) etc.; fuel elements and assemblies; alloys and mixtures; UF_4 or UF_6 (≥50% enriched)	C	≥6	≥2<6	≥0.4<2	<0.4
LOW-GRADE MATERIALS Solutions (1 to 25 g/L), process residues requiring extensive reprocessing; Pu-238 (except waste); UF_4 or UF_6 (≥20% < 50% enriched)	D	N/A	≥16	≥3<16	<3
ALL OTHER MATERIALS Highly irradiated forms[2], solutions (<1g/L), compounds; uranium containing <20% U-235 or <10% U-233 (any form, any quantity)[3]	E	N/A	N/A	N/A	See note 1

Note 1 The lower limit for Category IV is equal to reportable quantities in DOE O 472.1.
Note 2 Highly irradiated is material sufficiently radioactive to ensure a high probability of failure of task(s) by an adversary.
Note 3 The total quantity of U-233 = (Contained U-233 - Contained U-235). The category is determined by using the Pu/U-233 side of this table.

Attractiveness is a categorization that reflects the relative ease of processing and handling required to convert the material from its current form to a nuclear explosive device. Attractiveness is designated by the letters A through E. Attractiveness levels are associated with the properties of the material and not how the material is stored or packaged. Having the material in a vault, packaged in a hard to open container, or in small amounts in many containers does not reduce the inherent attractiveness of the material. It might make the material hard to access or accumulate and allow for more flexibility in protecting the material, but the inherent attractiveness level of the material remains the same.

The attractiveness level and amount of material determines the category. The category is designated by a Roman numeral, ranging from I to IV. For example, a pure plutonium oxide would be classified as attractiveness level C. Having 200 grams of Pu in that oxide would equal a category III quantity (pure oxide is 88 wt% Pu so the oxide weight is 230 g). Having more than 6 kg of Pu as a pure oxide would equal a category I quantity. In Table I, some attractiveness levels have N/A for the quantity under certain categories. This means that there is no quantity of material of that particular attractiveness level that would equal that category. For example, attractiveness level E material will always be category IV, no matter how much material is present. Conversely, any amount of attractiveness level A material is category I.

The category of material that is in a facility is one factor that determines the facility importance rating [4]. Facility importance ratings are used to identify the level of protection applicable to security assets and activities for those facilities. These ratings are designated by the letters A-E, PP, and NP. Table II is an abridged table from DOE O 470.4B, *Safeguards and Security Program*, 7-21-2011, describing the facility rating as it applies to categories of SNM.

Table II. Facility Importance Rating.

Facility Importance Rating	Criteria
A	Authorized to possess Category I quantities of SNM (including facilities with credible rollup quantities of SNM to a Category I quantity).
B	Authorized to possess Category II quantities of SNM.
C	Authorized to possess Categories III and IV quantities of SNM or other nuclear materials requiring safeguards controls or special accounting procedures.
D	Facilities that provide common carrier, commercial carrier, or mail service and are NOT authorized to store nuclear material during non-working hours.
E (Excluded)	This facility rating is not applicable to SNM or nuclear material.
PP (Property Protection)	Nuclear materials requiring safeguards controls or special accounting procedures other than those categorized as types “A,” “B,” or “C.”
NP (Non-Possessing)	Facilities whose staff has authorized-access SNM at other approved locations, but which do not themselves possess SNM.

The SNM criteria listed are sufficient to assure the facility importance rating; however, there are other criteria that can determine the facility rating, such as the level of classified matter allowed in the facility or the value of government property in the facility. For example, the WIPP is a property protection area because of the amount of government property it contains, but it is not required to have safeguards controls or special accounting procedures for SNM. The normal operating condition for the WIPP is that waste drums received will not have any safeguards requirements. In other words, all safeguards must be terminated prior to sending waste to the WIPP.

TERMINATION OF SAFEGUARDS

There are four conditions that must be met to terminate safeguards on nuclear material [2]:

1. The nuclear material must be of no programmatic value to DOE.

2. If the nuclear material is in a form that meets the criteria for attractiveness level E, then no additional approval needs to be obtained if all other conditions are met. If the nuclear material is attractiveness level D or higher, approval to terminate safeguards must be received from the DOE departmental element after consultation with the Office of Health,

Safety and Security (HSS). For NNSA facilities, approval to terminate is received from the Associate Administrator for Defense Nuclear Security after consultation with HSS.

3. The nuclear material being written off the accounting record system will be transferred to decontamination and decommissioning (D&D) or a waste management reporting identification symbol (RIS).

4. The nuclear material for which safeguards have been terminated will not be co-located with nuclear materials which are still in the accountability system for safeguarded materials.

Termination of safeguards is routine for those nuclear materials where the final waste form meets the criteria for attractiveness level E. For most sites, the responsible DOE or NNSA office has documented that these types of wastes have no programmatic use and site procedures for packaging, handling, storing, and shipping to meet conditions (3) and (4) are in place and well exercised. For nuclear materials of higher attractiveness, safeguards termination must be requested and approved. It should be noted that in past DOE orders, assignment of attractiveness level was more prescriptive and, in some instances, nuclear materials were assigned a higher attractiveness level than warranted [5]. Most of these instances have been found and corrected, but there may be some older materials that are still identified at the higher attractiveness level. The remainder of this discussion assumes that the appropriate attractiveness level has been assigned to the material.

For termination of safeguards on nuclear materials that are attractiveness level D, two different and equally successful strategies have been used throughout the DOE and NNSA complex. Both need approval as described in condition (2). The first strategy is simply to process the attractiveness level D material into a form that meets the criteria for attractiveness level E. This option has not been exercised very often because it usually increases the final waste form volume significantly (factors of 10 to 20 are not uncommon) or might involve costly processes, such as vitrification or cementation. The second and more common approach has been to perform a security analysis to show that when the attractiveness level D nuclear material is declared waste and transferred to waste management, the addition of this nuclear material in the waste management storage area does not significantly increase the risk of adversarial actions by either an insider or outsider threat.

Risks evaluated in the security analysis usually include the probability of obtaining a category II quantity for purposes of theft or increased risk of radiological sabotage. Because waste destined for the WIPP must meet a common waste acceptance criterion (WAC) and those criteria are not dependant on nuclear material attractiveness, it follows that it would be difficult to identify and then accumulate attractiveness level D drums based on waste acceptance information alone. This, combined with uniform WAC criteria that limit quantities of nuclear waste that can be packaged per container, has made it possible for sites to manage and discard (directly to WIPP) attractiveness level D material without processing the material to attractiveness level E.

Historically, the termination of safeguards on nuclear materials that are attractiveness level C follows a two-step process, which takes advantage of the success in terminating safeguards on attractiveness level D nuclear material. First, the attractiveness level C materials are processed to meet attractiveness level D criteria. Then, safeguards are terminated on the D material through a security analysis as described above. The most common processing method to reduce the attractiveness level of the C material is blending with chemical compounds that result in a mixture that is significantly less attractive because of reduced plutonium solubility, increased processing complexity, and decreased recovery efficiency.

Rocky Flats Plant (RFP) performed some of the first work on these chemical additives with performance testing done at PNNL [6]. At RFP, where possible, a residue containing larger weight percentage plutonium was down-blended with a less pure residue of the same material to reduce the attractiveness level of the final material to D. However, it was recognized that certain residue categories with higher concentrations of Pu could not be down-blended in this fashion. A concept named stardust was developed and tested on actual RFP residues, which provided blending material for higher concentration residues.

Stardust was a mixture of chemical components that could be added to the RFP residues to change the physical and chemical characteristics of the residues and make it more difficult and more complex to recover, concentrate, and purify the plutonium. The Rocky Flats studies grouped the chemical additives by the property they displayed during attempted recovery, such as cementing agents, gelling agents, thickening agents, and foaming agents, as well as other general additives. The specific chemicals were tested separately and in combination to see which achieved the best results for specific matrices. Tests done on ash and salt showed that this was a very successful technique to reduce attractiveness of C nuclear material to D. This technique has been proposed for the disposition of a portion of the 6 MT of surplus plutonium at Savanna River Site [7].

Attractiveness level B nuclear material is usually a metal. The same termination strategy that is used for excess, no-programmatic-use attractiveness level C nuclear material is also used for B material. In most cases, this becomes a three step process, lowering the attractiveness from level B to level C by oxidizing the metal to an oxide, blending the oxide with chemical additives to reduce the attractiveness from C to D, and then terminating safeguards through a security analysis. Once safeguards are terminated and the material is declared waste, it can be packaged to be certified for disposal at the WIPP.

PACKAGING FOR SHIPMENT TO THE WIPP

The requirements and criteria for acceptance of defense TRU waste at the WIPP describe the controlling (most restrictive) requirements to be used by sites in preparing their waste for transportation and disposal at the WIPP. In some instances, the WAC and regulatory requirements are synonymous. Waste acceptance is based on two specific categories of waste, defense TRU contact-handled (CH) waste (maximum external dose rate of 2 mSv/hr) and defense TRU remote-handled (RH) waste (external dose rate > 2 mSv/hr and ≤ 10 Sv/hr). To date, almost all of the material disposed of at the WIPP for which safeguards have been terminated has been defense TRU CH waste.

The WAC for TRU CH waste is divided into 6 broad categories [8]:

1) WAC associated with the WIPP authorization basis
2) Container Properties
3) Radiological Properties
4) Physical Properties
5) Chemical Properties
6) Data Package Contents

The first 5 of these categories are based on the inherent chemical and physical properties of the waste, whereas the last is more prescriptive. It is usually a single criterion that limits the amount of waste that can be shipped to the WIPP in a single payload container. In most cases, material blended to reduce its attractiveness level will easily meet all of the WAC, with the most restrictive being the two radiological properties of Pu-239 equivalent curie (PE-Ci) limit and Pu-239 fissile gram equivalent (FGE) limit, which determine payload size and configuration.

The concept of Pu-239 equivalent activity is intended to normalize all radionuclides in a waste payload container to a common radiotoxic hazard index for modeling routine and accident-related release hazards. Based on these models, each payload container type authorized for waste disposal at the WIPP has an upper PE-Ci limit. The pipe overpack component (POC) is a robust container with the highest PE-Ci limit (1,800 PE-Ci) of all the authorized payload containers (equivalent to 66.6 TBq). In contrast, a direct-loaded 208-liter (55-gallon drum) has a PE-Ci limit of 80 PE-Ci (2.96 TBq).

Similar to the PE-Ci concept, all of the fissile materials are identified in terms of Pu-239 FGE. The Pu-239 FGE limits are derived from nuclear criticality safety evaluations specific to the WIPP CH waste handling, storage, and disposal configurations. The fissile mass and moderator/reflector limits for each authorized payload container type, as well as the CH waste handling storage and disposal configuration at the WIPP, ensure that the probability of an inadvertent criticality is less than 10^{-6} per year for all normal and credible abnormal conditions. The POC and 208-liter drum each have a Pu-239 FGE limit of 200 grams. However, the TRUPACT-II shipping package has a total Pu-239 FGE load limit for 208-liter drums of 325 Pu-239 FGE, versus 2,800 Pu-239 FGE (14 payload drums per TRUPACT-II) for the POC [9]. The Pu-239 FGE limit in the TRUPACT-II is the most restrictive criteria, and for this reason, terminated materials are usually packaged in a POC for shipment to the WIPP.

CRITICALITY CONTROL OVERPACK WITH HIGHER PU-239 FGE LIMITS

There is an increased potential for disposition of large quantities of nuclear material as waste at the WIPP in support of NNSA consolidation to a less expensive infrastructure with fewer facilities and fewer storage areas for SNM. To better support this effort, the WIPP is in the process of certifying a new container that will facilitate transport and disposal of nuclear waste. This new shipping container is called the criticality control overpack (CCO). It is constructed by placing a criticality control container, which is manufactured from standard stainless steel ASME pipe and flange components, within a Department of Transportation (DOT) Type A 208-liter drum, using upper and lower laminated plywood dunnage (Figure 1). The CCO is lighter (approximate empty weight 104 kg/230 lb) than the POC. The WIPP is targeting an approximately 370 Pu-239 FGE limit for the CCO, almost 2 times the limit for a POC.

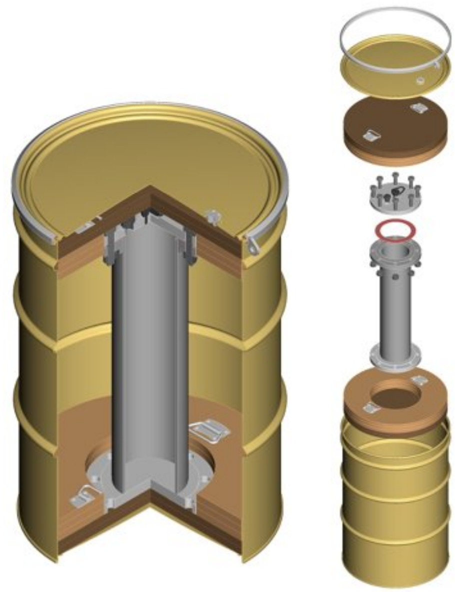

Fig 1. Criticality control container.

The CCO will more than double shipping efficiency and is expected to be significantly cheaper than the POC. Because of DOT weight limitations, the typical shipment for nuclear materials that have safeguards terminated is 35 POC's. Because the CCO is lighter, this will allow for 3 fully-loaded TRUPACT-II's, or 42 CCO's per shipment. The result is more than a doubling of the amount of material that can be transported in a single shipment. Container cost savings are significant. Because the construction materials are standard ASME components, the container is expected to be 60-70% the cost of a standard POC. By doubling the Pu-239 FGE loading, this further reduces the cost to the sites and for transportation.

For example, to move 100,000 Pu-239 FGE (100 kg) would require 500 POC's, which would cost approximately $1.4 million and require 15 full shipments. On the other hand, the same quantity would require 270 CCO's, which would cost approximately $0.46 million and require 5 full shipments. The cost savings scales as the quantity scales.

CONCLUSION

Retrieval, compliant packaging and shipment of retrievably stored legacy TRU waste has dominated disposal operations at WIPP since it began operations 12 years ago. But because most of this legacy waste has successfully been emplaced in WIPP, the TRU waste clean-up focus is turning to newly-generated TRU materials. A major component will be transuranic SNM, currently managed in safeguards-protected vaults around the weapons complex. As DOE and NNSA continue to consolidate and shrink the weapons complex footprint, it is expected that significant quantities of transuranic SNM will be declared surplus to the nation's needs.

Safeguards termination of SNM varies due to the wide range of attractiveness level of the potential material that may be directly discarded as waste. To enhance the efficiency of shipping waste with high TRU fissile content to WIPP, DOE designed an over-pack container, similar to the pipe component, called the criticality control over-pack, which will significantly enhance the efficiency of disposal. Hundreds of shipments of transuranic SNM, suitably packaged to meet WIPP waste acceptance criteria and with safeguards terminated have been successfully emplaced at WIPP (primarily from the Rocky Flats site clean-up) since WIPP opened. DOE expects that thousands more may eventually result from SNM consolidation efforts throughout the weapons complex.

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