Managing the Retrieval Risk of Buried Transuranic (TRU) Waste with Unique Characteristics

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ABSTRACT

United States-Department of Energy (DOE) sites that store transuranic (TRU) waste are almost certain to encounter waste packages with characteristics that are so unique as to warrant special precautions for retrieval. At the Hanford Site, a subgroup of stored TRU waste (12 drums) had special considerations due to the radioactive source content of plutonium oxide (PuO_2), and the potential for high heat generation, pressurization, criticality, and high radiation. These characteristics bear on the approach to safely retrieve, overpack, vent, store, and transport the waste package. Because of the potential risk to personnel, contingency planning for unexpected conditions played an effective role in work planning and in preparing workers for the field inspection activity. As a result, the integrity inspections successfully confirmed waste package configuration and waste confinement without experiencing any perturbations due to unanticipated packaging conditions. This paper discusses the engineering and field approach to managing the risk of retrieving TRU waste with unique characteristics.

INTRODUCTION

Suspect TRU wastes have been retrievably stored in the Hanford Site Low Level Burial Grounds (LLBG) from 1970 through the 1980s. Fluor Hanford, Inc. has undertaken the Waste Retrieval Project to retrieve 4,200 m^3 of suspect TRU waste from the LLBG by September 30, 2006.

A subgroup of this waste, 12 drums, had unique characteristics that were outside the current typical drum removal activities. These 12 drums contain various isotopes of plutonium along with the decay products of Am-241 and U-234, all in oxide form. Because of the high percentage of Pu-238, these drums were referred to as the Hanford Pu-238 drums. Of particular interest was the condition of the drum, the concentric containers in the drum, and the oxide contained in the innermost container. Evaluation of the concentric containers was needed to develop a specific plan for the safe removal of these 12 drums.

The LLBG consists of trenches where waste in various sized packages is stored for future removal and processing. The particular trench where the 12 drums were stored is made up of modules that are equivalent to a horizontal array of 12 by 12, 208-L drums that are vertically stacked four tiers high. Plywood separates each tier. A tarp covers the entire stacked array from top to bottom. A final layer of plywood covers the tarp and approximately 1.2 m of soil covers the final layer of plywood.

Field measurements were needed to assess that (1) the Pu-238 drum’s confinement condition had not been significantly altered as a result of drum service; (2) the package configuration was as described in the Calculations for the Hanford Pu-238 Drums [1]; and (3) the package was contact handled retrievably stored waste. The field effort was referred to as the Pu-238 Drum Integrity Inspection and was designed to affirm container integrity as follow-on to the engineering assessment reported in Reference 1.

The field assessment approach was to use standard waste retrieval methods for uncovering the drum(s) and use off-the-shelf nondestructive examination technologies that could be safely deployed in the LLBG trench and provide a reasonable expectation of useful data for imaging, radiation, and temperature. Even though the drum integrity assessment [2] predicted that the Pu confinement barriers should be intact, there was a remote possibility that confinement may have been lost. Since personnel safety was paramount, contingencies were analyzed and responses specific to the hazards of the Pu-238 drum inspection activities were developed during the Preliminary Hazards Analysis, the job-specific Automated Job Hazard Analysis, and the Unreviewed Safety Question process.

DRUM STORAGE

Each of the 12 drums contains a shipping container that was assembled at the Savannah River Site (SRS) in 1966 and shipped to Hanford where the drums were stored above-ground for approximately 14 years. In 1980, the drums were buried in the LLBG. The container packaging consists of multiple, concentrically nested containers. The PuO_2 was sealed in two, nested aluminum cans that were enclosed in a stainless steel source capsule. The source capsule was positioned in a carbon steel shipping container with the annulus filled with aluminum pellets. The shipping container was centered in a 208-L drum by means of a birdcage type structure as illustrated in Fig. 1. Knowledge of the package configuration was based on a combination of incomplete historical drawings and correspondence.

The 12 drums were buried in 1980 on the top tier of one of the LLBG modules. The 12 drums were spaced to meet the requirements for heat dissipation. To complete the array, other 208-L waste drums were placed around the 12 drums on tier 4 and the tiers below as illustrated in Fig. 2.

TECHNICAL APPROACH

The engineering analyses showed a low probability of the confinement failing. Yet, the high consequences of a failed container to the safety of the workers during inspection and subsequent retrieval warranted in-field inspection to verify as much of the confinement and configuration condition as possible prior to retrieving the drums. Lessons learned [3] from a DOE Type B investigation of worker uptakes at Los Alamos National Laboratory [4] concluded that packages containing radioactive material should be assumed unsafe until proven otherwise.

The engineering assessment [1] discovered discrepancies among the historical documentation regarding the exact package configuration. Specifically, the SRS engineering drawing of the source capsule was not available in the Hanford Site records nor was it retrievable by SRS to allow for verification of the source capsule design. Other engineering drawings raised the possibility that the source capsule was of a different configuration and material. The possibility also existed that the source capsule was surrounded by felt rather than aluminum pellets.

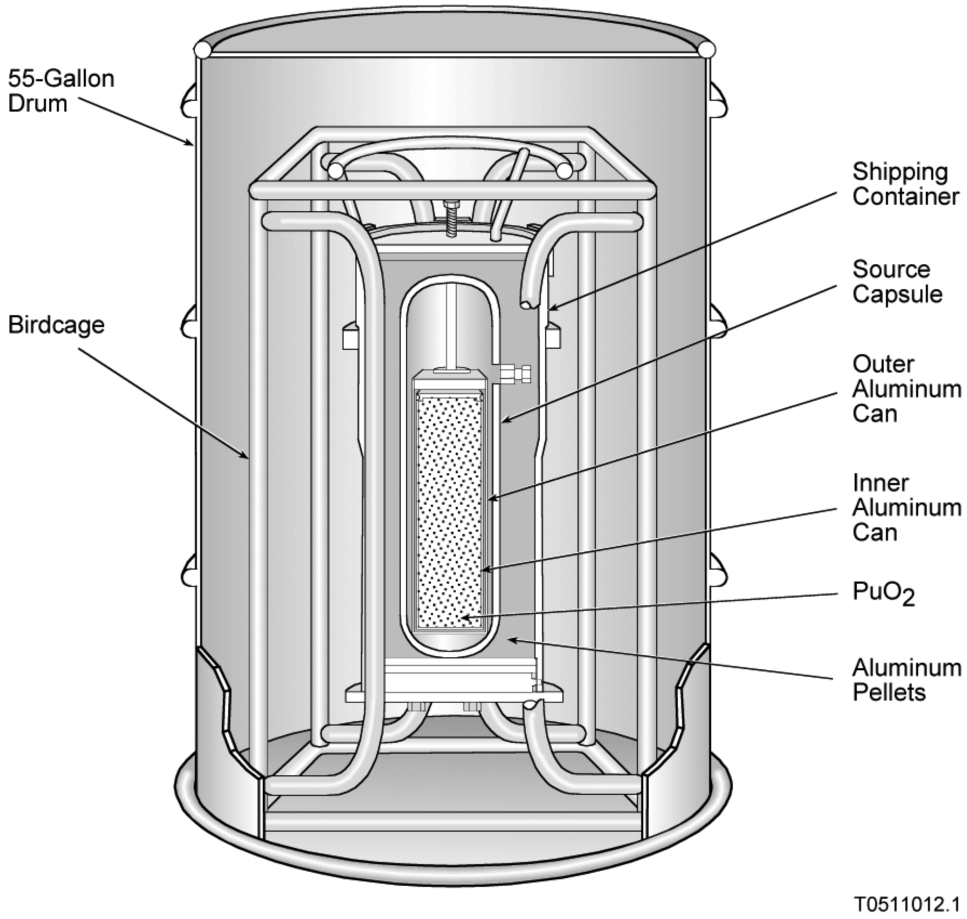

Fig. 1. Pu-238 Drum with birdcage and source capsule with nested aluminum cans of plutonium oxide

Fig. 2. Burial Trench showing four tiers of waste containers

Determination of the necessary precautions for safe handling began with an early engineering assessment [1]. The assessment included a review of the inner container materials and the potential impact on confinement resulting from service history. The assessment considered packaging details and records, service history of the package, corrosion, thermal aging, stress corrosion cracking, intergranular attack, and embrittlement. Given the expected configuration of the containers, the engineering assessment predicted one could reasonably expect container performance at the time of retrieval to match container performance at the time of packaging [1].

The purpose of the drum integrity inspection was to evaluate and confirm the confinement condition of the internal source capsule, packaging configuration, and provide insight into the material of construction for the contents of each drum. The first three drums were inspected without removing the drums from their storage location in the array. This was to gain as much information as possible on the drum condition and configuration before operator handling of the drum. The soil overburden, plywood, and tarp were incrementally removed to expose only three drums at a time, as required by the physical security plan. Initially, three of the 12 drums were exposed, measured, and radiographed. A post job review was conducted and lessons learned factored into the planning for inspecting the remaining nine Pu-238 drums.

Primary attributes for assessing confinement included radiation dose levels, presence of external contamination that had originated from the source capsule, and temperature resulting from radiolytic decay. For example, the engineering assessment predicted an expected combined photon and neutron dose rate of approximately 0.23 to 0.26 mSv/hr [1]. Complete failure of the packaging was calculated to result in dose rates exceeding 15 mSv/hr. Pu-238 contamination, if found on the external surface of the drum in isotopic concentrations similar to that of the oxide contained within the source capsule, would be a clear indicator that confinement had failed. Heat from radiolytic decay was predicted to be within 5.7 °C of an adjacent container that has been stored in same environmental conditions. A higher differential temperature (ΔT) could indicate unexpected conditions inside the drum.

After the confinement condition was verified for an individual drum, radiography was used to confirm the package configuration. Overpacking and above ground storage would proceed if all attributes were “as expected”. After the drum was overpacked, it was placed in above ground storage awaiting future off-site shipment to SRS. The process was repeated until all 12 drums were inspected.

Contingency Planning

Since the purpose of drum integrity inspection was to confirm confinement, field activities had to assume potential loss of confinement. This led to planning contingencies should loss of confinement be discovered. Potential hazards and unexpected drum conditions were identified, analyzed, and contingency plans developed by an inter-disciplinary team consisting of representatives from the organizations: operation, radiation control, industrial health and safety, nuclear safety, and engineering. A logic diagram was prepared of the steps planned for inspection activities and included decision points based on the potential field condition of the drums.

When expected conditions were verified, the decision point allowed the next step in the logic to proceed. If unexpected conditions were found, the decision point identified the needed contingency action. Contingency action planning involved the line organizations, thereby strengthening the thoroughness of the work planning and worker buy-in.

Drum conditions included elevated dose rate, drum identification not identifiable, elevated drum temperature, corroded drum, drum not in expected position, bulging drum, damaged drum, contaminated drum, and drum configuration not as expected.

Complete or catastrophic failure of the internal packaging would be clearly indicated by a high radiation dose rate. In the case of catastrophic failure, the oxide would be repositioned from the inner containers to the bottom of the drum. The dose rate was estimated to increase by two orders of magnitude primarily from the Am-241 which had accumulated as a decay product in the oxide. However, the contingent actions recognized that partial failure of the confinement boundaries would produce field attributes lower than that for catastrophic failure (i.e., something less than the estimated two orders of magnitude increase in dose rate).

Cautionary limits and decision points were set for dose rate, contamination, and temperature. If these limits were reached, then a management review committee (MRC) would review the field conditions and determine specific actions to respond to the field conditions. The members of MRC were the facility manager, the operations manager, the radiological control manager, and the engineering manager. Technical disciplines from other support organizations (e g., nuclear safety, industrial hygiene, and environmental compliance) would be consulted depending on the specific situation.

For dose, a limit of 0.50 mSv/hr on contact (total photon and neutron) was established for the field as a cautionary dose rate limit that, if reached, would temporarily halt inspection activities while the MRC reviewed the available data and provided further instruction to the field. The field may be directed to obtain further corroborating data. Since the predicted dose rate was estimated to be 0.23 to 0.26 mSv/hr, the 0.50 mSv/hr limit was chosen by engineering as an indication that a confinement breach may have occurred warranting a review by the MRC before proceeding any further with inspection. The 0.50 mSv/hr engineering limit was below the limit of 3.00 mSv/hr established in the radiation work permit as the maximum allowable dose rate for typical inspection activities.

The cautionary limit for contamination was set at detectable levels. Isotopic analysis would be performed to verify if the source of contamination, either as PuO_2 or contamination from other drums in the array.

A ΔT of 16.7 °C between a drum containing PuO_2 and an adjacent drum was established as the cautionary limit that would invoke MRC action. Since the predicted ΔT was 5.7 °C, the established 16.7 °C provided an acceptable margin of error to account for uncertainties in the predicted value while maintaining worker safety.

Potential drum conditions were assessed, measurable primary and secondary attributes preset, and potential actions determined if preset cautionary limits were exceeded. If a drum exceeded a cautionary limit, two possible conclusions were possible: 1) the exceeded attribute did not by itself identify a failed inner container and further evaluation was needed or 2) the exceeded attribute indicated a failed inner container and an Unreviewed Safety Question and Potential Inadequacy in the Safety Analysis determination was required. The planning also recognized that these cautionary limits could occur independently or in combination. For example, since the source of heat was primarily from the decay of the Pu-238 within the PuO_2, there should have been a corresponding increase in dose rate with an excessive increase in ΔT.

Possible confinement and configuration conditions, and potential response actions were reviewed with the field workers and management. These potential response actions were simulated and practiced prior to starting the actual inspection activity in the field.

One contingency was independent of drum condition. During deployment or retrieval of the radiography source, the source itself could become stuck in an unshielded position between its shielded case and the collimator. Since the maximum allowable source the radiographer was licensed to use was 3.7 E12 Bq of Ir-192, the estimated dose rate of an unshielded source was estimated to be 6.0 Sv/hr at 30 cm. This full dose rate would also occur during the normal three seconds it took for the source to travel to or from its shielded case to the collimator. If this source became stuck between these two points, then contingency actions would be required by the radiographer, per his Nuclear Regulatory Commission license, to recover the stuck source.

As Low As Reasonably Achievable (ALARA) Considerations

The use of radiography as a part of drum retrieval was new to LLBG operations. Therefore, radiographing the Pu-238 drums was preceded by radiographing a non-radioactive drum (mockup) that was representative of a Pu-238 drum. The decision to proceed with radiographing the Pu-238 drums depended on the successful radiographing of the mockup. The purpose of radiographing a mockup was to demonstrate that radiographic techniques would yield useful information prior to deploying radiography services in the LLBG and to minimize experimentation while in the trench. If successful, cycle times for setup, exposure, and film developing would be factored into the work planning and hazard analyses.

The radiographic equipment was assembled at the Waste Retrieval Project Simulated Test Site. Here the off-site contractor performing radiography familiarized the Fluor Hanford personnel from operation, radiation control, and engineering with the safety boundaries, access control requirements during radiography, and the operation of the radiography equipment. Special training of the radiation control technicians was provided by the subcontractor to familiarize them with the radiography source equipment. Responses to a potential stuck source were simulated, and the interaction between the radiographer, field personnel, and the MRC were practiced as a part of contingency planning. In addition, responses to contingency actions were simulated for an elevated dose rate and a bulged drum. Through the job hazard analysis and radiological work screening processes, it was determined that placing an earth berm to shield the radiographer's exposed source was the most effective way to shield workers during normal and unexpected conditions.

Understanding the risks, identifying contingent actions, and practicing the response to these potential conditions served two ALARA purposes for both normal and unexpected events. First, in the event of an unexpected condition, contingent actions would keep radiation exposures to a minimum. Second, the operators, radiation control technicians, and the radiography contractor learned each others' roles and responsibilities during normal and unexpected conditions.

RESULTS

While engineered drawings for the source capsule were unavailable, the radiographs agreed with historical correspondence and criticality documentation. Radiation dose and temperature data were within the values predicted by earlier engineering calculations [1].

The 12 drums were packaged by the same generator; were limited in number; and had experienced the same environmental conditions. While in all likelihood the condition of the remaining nine drums would be similar to the first three drums inspected, protecting the immediate workers still remained the focus during inspection activities. The approach for the remaining nine drums remained fundamentally the same, except where field conditions or operational improvements warranted modification to the work instructions.

Based on the inspection results of the initial three drums, work instructions were modified to account for changing conditions. For example, the soil overburden and surrounding drums provided shielding during radiography. However, as more drums were uncovered and removed to provide access to the remaining Pu-238 drums, shielding was gradually lost. To maintain dose rate control as the surrounding shielding was removed, the work instructions were modified to allow the drum to be moved to a location on tier 4 of the array where shielding would still be adequate for radiography. The drum was moved only if dose, contamination, and temperature were within expected values.

Radiation Dose and Contamination

Data on radiation dose rate were collected for the first three drums as the distance to the drums decreased. During bulk mechanical excavation, dose rate readings were taken as every 30 to 45 cm of soil were removed. After the side and top soil overburden was mostly removed by machine, hand digging was used to determine the top leading edge of the first row of drums. Dose rate readings that were taken at 30 cm and at contact confirmed the dose rate was as expected. After confirmation of dose rate, final excavation was completed and dose rate readings were taken on the face of each exposed drum. This data confirmed that the location of each Pu-238 drum was consistent with existing burial records. Surface smears that were taken to detect possible contamination were negative. Table I compares the dose rate readings with predicted dose rate. Some of the dose readings were outside the predicted values, but all were within the established cautionary limit of 0.50 mSv/hr.

After the initial three drums were surveyed, dose and contamination on the remaining nine drums were monitored, but recorded only for the Pu-238 drums.

Table I. Comparison of Pu-238 Drum at Contact Dose with Predicted Dose

Pu-238 Drum Dose Rate @ Contact - Exposed Face (mSv/hr)				
Drum Number	**Beta - Gamma**	**Neutron**	**Total Dose**	**Predicted Total Dose [1]**
T-102	0.12	0.10	0.22	0.23 - 0.26
T-103	0.20	0.14	0.34	0.23 - 0.26
T-104	0.13	0.12	0.25	0.23 - 0.26
T-105	0.15	0.11	0.26	0.23 - 0.26
T-106	0.18	0.14	0.32	0.23 - 0.26
T-107	0.10	0.05	0.15	0.23 - 0.26
T-108	0.20	0.10	0.30	0.23 - 0.26
T-109	0.15	0.13	0.28	0.23 - 0.26
T-110	0.15	0.07	0.22	0.23 - 0.26
T-111	0.10	0.07	0.17	0.23 - 0.26
T-112	0.20	0.14	0.34	0.23 - 0.26
T-113	0.15	0.25	0.40	0.23 - 0.26

Temperature

Collection of temperature data paralleled that for radiation dose rates. As with dose, temperature data were collected as the top edge of the initial three Pu-238 drums was exposed. Drum temperature followed dose rate and contamination readings. After the initial three drums, temperatures on the remaining nine drums were monitored, but recorded only for the Pu-238 drums. Table II compares actual drum temperatures with predicted values. The temperatures of the Pu-238 drums compared to an adjacent drum were within the ΔT predicted.

Table II. Temperature Comparison of Pu-238 Drums and Adjacent Drums with the Predicted Difference

Pu-238 Drum Temperature Summary - Exposed Face (ºC)				
Drum Number	**Pu-238 Drum**	**Adjacent Drum**	**Difference**	**Predicted Difference [1]**
T-102	21.1	20.0	1.1	5.7
T-103	54.4	48.9	5.6	5.7
T-104	38.3	34.4	3.9	5.7
T-105	26.4	23.9	2.5	5.7
T-106	43.9	33.9	10.0	5.7
T-107	20.0	17.8	2.2	5.7
T-108	24.4	22.8	1.7	5.7
T-109	49.7	54.4	-4.7	5.7
T-110	19.4	17.8	1.7	5.7
T-111	22.8	23.9	-1.1	5.7
T-112	56.7	61.7	-5.0	5.7
T-113	31.1	26.1	5.0	5.7

Radiography

After dose and temperature measurements, radiography was performed and provided a qualitative look inside each of the Pu-238 drums, as needed to permit handling the drum and eventual processing by the SRS. The radiographs focused on two aspects of the drum contents: the birdcage and the source capsule.

Of interest were the configuration of the internal packaging, the presence of the vent plug, and the structural integrity of the bird cage. An initial radiograph was taken to determine the orientation of the vent plug on the source capsule of each Pu-238 drum. The radiographic equipment was then repositioned to obtain a profile of the vent plug. Radiographic film was placed directly behind the drum and duplicate radiographs were shot to provide both Hanford and SRS with a record of the inspection of each drum. Radiographs of the first three drums indicated that the drum containment was as expected. The structural integrity of the birdcage was important since the documented safety analysis took credit for the spacing provided by the birdcage. The birdcage radiographs indicated no change in geometry compared to the drawings. Fig. 3 and Fig. 4 are radiograph photographs illustrating characteristics of the source capsule and internal aluminum cans. Detailed examination of the radiographs clearly showed the individual aluminum can walls, the aluminum can Magneform® sealed tops, the conical vent plug, and the shape of the plutonium oxide in the bottom of the can. In some cans, objects were observed that may have been used to load the oxide into the cans.

CONCLUSIONS

The field integrity inspection verified key physical and radiological attributes, and the conclusions of the engineering assessment [2]. All 12 drums were safely inspected, retrieved, overpacked, vented, and stored pending shipment off-site for final disposition. No safety or conduct of operations issues were experienced during the entire process. The inspection and handling of these 12 Pu-238 drums demonstrated the value of performing the upfront engineering assessments and developing the appropriate planning for operational precautions and contingencies for field inspections and waste removal. Looking to the future, Hanford’s TRU Waste Retrieval Project has identified 50 distinct waste streams of which over 20 waste streams have unique characteristics, and more will likely be identified as retrieval progresses. The thorough planning also validated the merit of worker involvement since it played a key role in determining how to address each contingency and perform the inspections.

Other DOE sites having a similar history of storing TRU waste generated on-site and off-site will experience analogous challenges and will benefit from applying a similar planning rigor for significant, unknown conditions. Elements of the engineering and operational rigor can be modified and appropriately applied to the unique characteristics of other TRU wastes at Hanford and other DOE sites.

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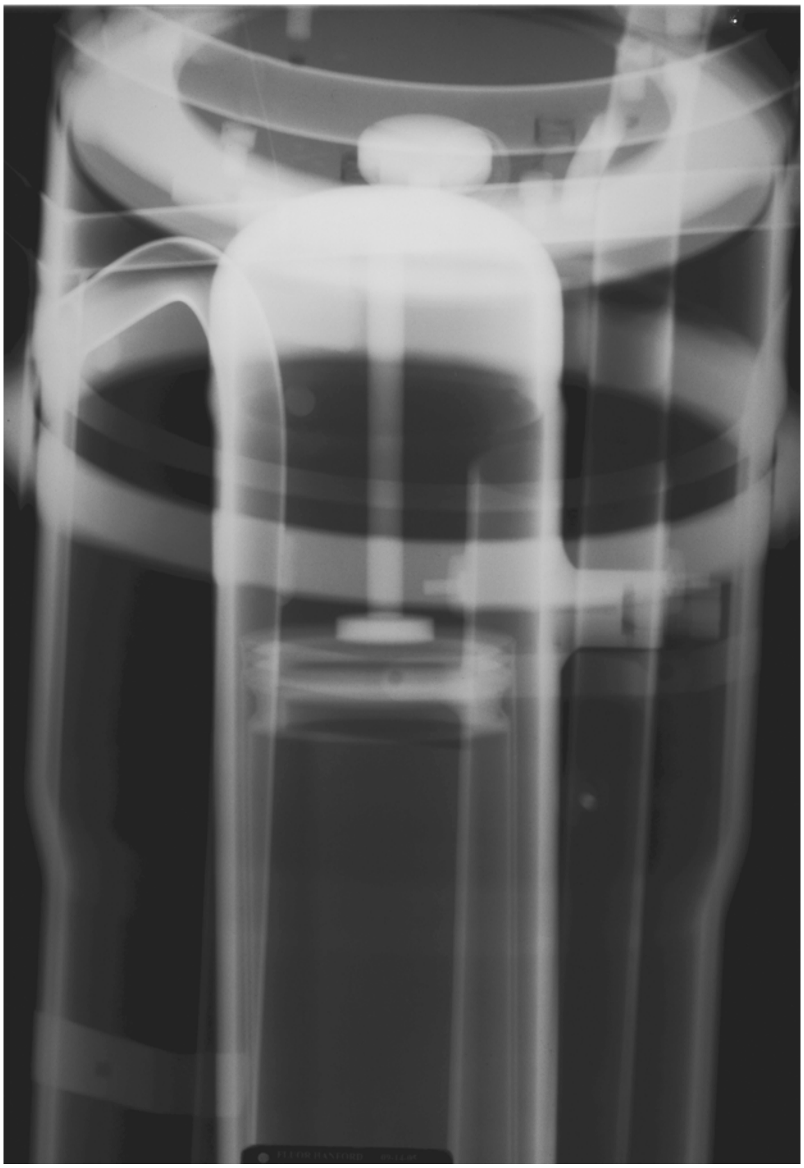

Fig. 3. Radiograph photograph of the top of a source capsule, vent plug, and nested aluminum cans.

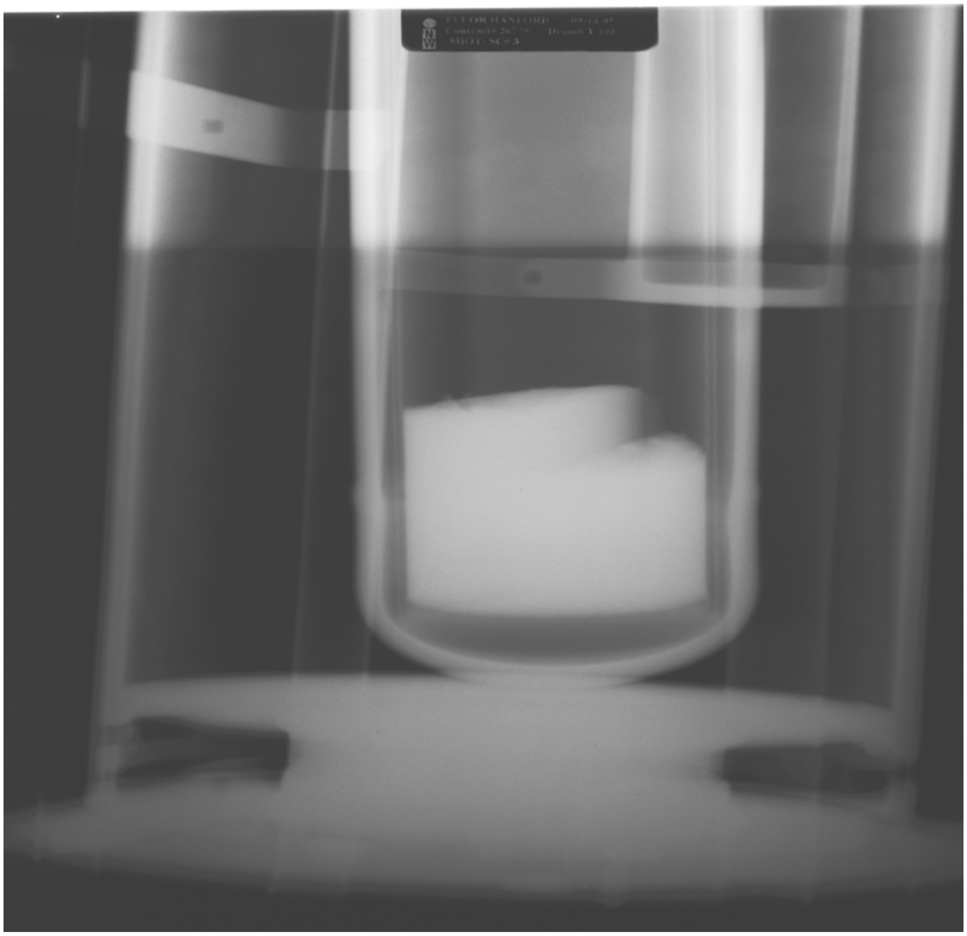

Fig. 4. Radiograph photograph of the bottom of a source capsule, the plutonium oxide, and a shipping container.