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Precedents for Authorization of Contents using Dose Rate Measurements

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Abstract

For the transportation of Radioactive Material (RAM) packages, the requirements for the maximum allowed dose rate at the package surface and in its vicinity are given in Title 10 of the Code of Federal Regulations, Section 71.47. The regulations are based on the acceptable dose rates to which the public, workers, and the environment may be exposed. As such, the regulations specify dose rates, rather than quantity of radioactive isotopes and require monitoring to confirm the requirements are met. 10CFR71.47 requires that "each package of radioactive materials offered for transportation must be designed and prepared for shipment so that under conditions normally incident to transportation the radiation level does not exceed 2 mSv/h (200 mrem/h) at any point on the external Surface of the package, and the transport index does not exceed 10." Before shipment, the dose rate of the package is determined by measurement, ensuring that it conforms to the regulatory limits, regardless of any analyses. This is the requirement for all certified packagings. This paper discusses the requirements for establishing the dose rates when shipping RAM packages and the precedents for meeting these requirements by measurement.

Background

For the transportation of Radioactive Material (RAM) packages, the requirements for the maximum allowed dose rate at the package surface and in its vicinity are given in Title 10 of the Code of Federal Regulations, Sections 71.47 and 71.51 (10 CFR §71.47 and 10 CFR §71.51) [Ref. 1] for normal conditions of transport (NCT) and hypothetical accident conditions (HAC), respectively. These CFRs require:

> 10 CFR §71.47 - "Each package of radioactive materials offered for transportation *must be designed and prepared for shipment* so that under conditions normally incident to transportation the radiation level does not exceed 2 mSv/h (200 mrem/h) at any point on the external surface of the package, and the transport index does not exceed 10."
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> 10 CFR §71.51 – "No external radiation dose rate exceeding 10 mSv/h (1 rem/h) at 1 m (40 in) from the external surface of the package."

The regulations are based on the acceptable dose rates to which the public, workers, and the environment may be exposed and mirror those found in 49 CFR 173.441. As such, the regulations specify dose rates, rather than quantity of radioactive isotopes and require monitoring to confirm the requirements are met. Before shipment, the dose rate of the package is determined by measurement, ensuring that it conforms to the regulatory limits, regardless of any analyses. This is the requirement for all certified packagings. However, there have occurred instances where either the definition of a bounding content was not possible, where definition of impurities within the RAM was not possible, where the physical form of the content made modeling and analysis not practical, or where the mixing of the RAM and impurities were not know and bounding calculations yielded dose rates that were unrealistic high and exceeded the 10 CFR §71 limits. In these cases, regulatory compliance of a package at the time of shipment has been established through dose rate measurements. This paper discusses the requirements for establishing the dose rates when shipping RAM packages and the precedents for meeting these requirements by measurement.

Discussion

Within the U.S. Department of Energy (DOE), DOE Order 460.1C [Ref. 2] defines the actions required of each entity prior to shipment of RAM. DOE Order 460.1C(2)(d) requires: "For a new DOE or NNSA Type B or fissile material packaging each entity must submit an application to the Certifying Official that includes a Safety Analysis Report for Packaging (SARP) and any other supporting documentation to demonstrate that the packaging meets the requirements of 10 CFR Part 71." Each certifying organization, the International Atomic Energy Agency (IAEA), the Nuclear Regulatory Commission (NRC), and the DOE, has guides and standards for assistance in the preparation of SARPs defining the minimum essential elements required to establish the safety basis for the RAM packaging. With respect to compliance with the dose rate limits the following are provided, with the pertinent passages italicized. It is noted that these requirements and guidance address the shielding calculations necessary to establish the package safety basis but also discuss confirmatory or compensatory measurements.

<u>IAEA Safety Standards TS-R-1 [Ref. 3]:</u>

> **Radiation Protection**
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> 301. *Doses to persons shall be below the relevant dose limits*. Protection and safety shall be optimized in order that the magnitude of individual doses, the number of persons exposed, and the likelihood of incurring exposure shall be kept as low as reasonably achievable, economic and social factors being taken into account, *within the restriction that the doses to individuals be subject to dose constraints*. *A structured and systematic approach shall be adopted* and shall include consideration of the interfaces between transport and other activities.

Determination Of Basic Radionuclide Values
402. For individual radionuclides which are not listed in Table 1 (Basic Radionuclide Values) the determination of the basic radionuclide values referred to in paragraph 401 shall require multilateral approval. It is permissible to use an *A_2 value calculated using a dose coefficient* for the appropriate lung absorption type, as recommended by the International Commission on Radiological Protection, if the chemical forms of each radionuclide under both normal and accident conditions of transport are taken into consideration.

Labeling for radioactive contents
544. Each label conforming to the models in Fig. 2, Fig. 3 and Fig. 4 shall be completed with the following information:
(b) Activity: The *maximum activity* of the radioactive contents during transport expressed in *units of becquerels* (Bq) with the appropriate SI prefix symbol. For fissile material, the mass of fissile material in units of grams (g), or multiples thereof, may be used in place of activity.

Contents specification for assessments of packages containing fissile material
673. *Where the chemical or physical form, isotopic composition, mass or concentration, moderation ratio or density, or geometric configuration is not known*, the assessments of paragraphs 677–682 shall be performed assuming that each parameter that is not known has the value which *gives the maximum neutron multiplication* consistent with the known conditions and parameters in these assessments.

674. For irradiated nuclear fuel the assessments of paragraphs 677–682 shall be based on an isotopic composition demonstrated to provide:
(a) the *maximum neutron multiplication* during the irradiation history, or
(b) a *conservative estimate of the neutron multiplication* for the package assessments. After irradiation but prior to shipment, a measurement shall be performed to confirm the conservatism of the isotopic composition.

807. An application for approval shall include:
(f) where the proposed radioactive contents are irradiated fuel, the applicant shall state and justify any assumption in the safety analysis relating to the characteristics of the fuel and describe *any pre-shipment measurement* required by paragraph 674(b)

<u>IAEA, Safety Standards ST-2 [Ref. 4]</u>

Low specific activity material
226.17. The following method is an example for LSA-III materials which are essentially uniformly distributed in a solid compact binding agent. The method is to divide the LSA material volume including the binding agent into a number of portions. At least ten portions should be selected, subject to the volume of each portion being no greater than 0.1 m3. The specific activity of each volume should then be assessed (*through measurements*, calculations or combinations thereof).

Overpack
229.2. A rigid enclosure or consolidation of packages for ease of handling in such a way that package labels remain visible for all packages need not be considered as an overpack unless advantage is taken by the consignor of the *determination of the TI of the overpack by direct measurement of the radiation level.*

Radiation level
233.3. In mixed gamma and neutron fields it may be necessary to *make separate measurements*. It should be ensured that the monitoring instrument being used is appropriate for the energy being emitted by the radionuclide and that the calibration of the instrument is still valid. *In performing both the initial measurement and any check measurement*, the uncertainties in calibration have to be taken into account.

233.5. The Regulations require that, at the surfaces of packages and overpacks, specific radiation levels shall not be exceeded. *In most cases a measurement made with a hand instrument* held against the surface of the package indicates the reading at some distance away because of the physical size of the detector volume.

Radiation Protection
302.4. Examples of derived limits in the Regulations include the maximum activity limits A_1 and A_2, maximum levels for non-fixed contamination, radiation levels at the surfaces of packages and in their proximity, and segregation distances associated with the transport index. *The Regulations require assessment and measurement to ensure that standards are being complied with*.

Determination Of Transport Index
(e) The TI for loads of uranium and thorium ores and their concentrates can be determined without measuring the radiation levels. Instead, *the maximum radiation level at any point 1 m from the external surface of such loads may be taken* as the level specified in paragraph 526(a). The multiplication factor of 100 and the additional multiplication factor for the largest cross-sectional area of the load are still required, when applicable as indicated above, for determining the TI of such loads.

526.3. The *TI is determined by scanning all surfaces of a package*, including the top and bottom, at a distance of 1 m. The highest value measured is the value that determines the TI.

Pre-shipment measurements
VII.72. When burnup credit is used in the package assessment, operational and administrative controls are needed to establish that the INF being loaded in the package is within the characteristics used to perform the safety evaluation. In paragraph 674(b) *a measurement is called for*, and it is appropriate to link the assessment to this measurement.

<u>Regulatory Guide 7.9 [Ref. 5]</u>

5.1.2 Summary Table of Maximum Radiation Levels
This section should present *the maximum dose rates for both normal conditions of transport and hypothetical accident conditions* at the appropriate locations for non-exclusive and exclusive use shipments, as applicable.

5.4.4 External Radiation Levels
This section should describe *the results of the radiation analysis* in detail. These should agree with the summary tables. The locations of maximum dose rates for the analysis should be identified, and sufficient data provided to show that the radiation levels are reasonable and their variations with location are consistent with the geometry and shielding characteristics of the package. The results should address normal and accident conditions.

NUREG-1609, Standard Review Plan [Ref. 6];

The Standard Review Plan for Transportation Packages for Radioactive Material provides guidance for the review and approval of applications for packages used to transport radioactive material under 10 CFR Part 71.

This document is intended for use by the U.S. Nuclear Regulatory Commission (NRC) staff. Its objectives are to (1) summarize 10 CFR Part 71 requirements for package approval, (2) describe the procedures by which the NRC staff determines that these requirements have been satisfied, and (3) document the practices developed by the staff in previous reviews of package applications.

5.5.1.2 Summary Table of Maximum Radiation Levels
Review the summary table of maximum radiation levels. Ensure that the maximum dose rates are presented for both normal conditions of transport and hypothetical accident conditions at the appropriate locations for non-exclusive or exclusive use (or both), as applicable.

UCID-21218, Packaging Review Guide [Ref. 7]

5.3.1.3 Summary Table of Maximum Radiation Levels
Review the summary table of maximum radiation levels. Ensure that the maximum levels are presented for both normal conditions of transport and hypothetical accident conditions at the appropriate locations for nonexclusive or exclusive use (or both), as applicable. A table is provided as an example of the information that should be presented for nonexclusive use. A similar table should be presented for exclusive use shipment as appropriate.

5.3.4 Shielding Evaluation
The review of the shielding evaluation presented in the SARP should consider that §71.87(j) *requires actual external radiation levels to be measured* prior to shipment in order to verify that the limits of §71.47 are not exceeded. Other factors that should be considered in determining the level of effort for the shielding review include the expected magnitude of the radiation levels, the margin between calculations and regulatory limits, similarity with previously reviewed packages, thoroughness of the review of source terms and other input data, and bounding assumptions in the analysis.

5.4.2 Conditions of Approval
The TRR should clearly identify any conditions of approval that should be included in Section 5 of the certificate of compliance.

Compliance by Dose Measurement

There are instances for RAM packages where the bounding dose rates for the package cannot be established with modeling and calculation. Three specific cases will be discussed. Case one involves the TRUPACT-II package where the definition of a bounding RAM content and impurities was not possible and where the physical form of the content made modeling and analysis not practical. Cases two and three involve the Savannah River Site Model 9975 package. In the first instance, high impurity plutonium and uranium metals and oxides shipped in the Model 9975 Packaging, the bounding RAM content and maximum impurities were defined but their morphology and mixing were not. The most conservative (and therefore bounding) mixing model yielded dose rates that were unrealistically high and exceeded the 10 CFR §71 limits in both NCT and HAC. The second instance, one of the cases for the 9975, involves the shipment of ^{233}U. ^{232}U occurs as a byproduct of ^{233}U production. The dose rates for the 9975 were intimately dependent on the very small amount of ^{232}U dispersed within, and inseparable from, the remaining RAM. The mass of ^{232}U acceptable for shipment within the 9975 could be increased with the use of lead shielding. In these cases, regulatory compliance of a package at the time of shipment has been established through dose rate measurements. This paper discusses the requirements for establishing the dose rates when shipping RAM packages and the precedents for meeting these requirements by measurement. The DOE Orders give the Certifying Official the authority to accept the safety basis established by the SARP with whatever additional conditions they deem to be appropriate.

Section 4(a), *Requirements* for Offsite Safety of DOE O 460.1C [Ref. 2] in Section (2)(a*), Special Requirements for Radioactive Material Packagings*; "Each entity that offers for transportation RAM in a Type B or fissile material packaging must *meet the conditions specified in the Certificate of Compliance (CoC) or Offsite Transportation Certificate (OTC), as appropriate, for the package issued by the HCO, NNSA CO or NRC.*

TRUPACT-II

The TRUPACT-II is authorized to ship solid wastes containing transuranic materials at a concentration greater than 100 nanocuries per gram. These waste materials are placed in Type A packages prior to placement within the TRUPACT-II. The modeling of these contaminated solid waste containers within the package was impractical. The TRUPACT-II SARP [Ref. 8] made the case for compliance with the dose rate limits based on 1) measurement of the individual payload container and verification that it met the dose rate limits without the use of additional shielding materials and 2) pre-shipment confirmatory dose rate measurements of the TRUPACT-II itself.

> 5.0 Shielding Evaluation
>
> The compliance evaluations of the TRUPACT-II packaging with respect to the dose rate limits established by 10 CFR 71.47(a) for normal conditions of transport (NCT) or 10 CFR 71.51(a)(2) for hypothetical accident conditions (HAC) are based on two categories. The first category does not permit the use of shielding materials to meet NCT or HAC dose rate limits and is evaluated in this section.

Each contact handled transuranic (CH-TRU) waste payload container (i.e., 55-gallon drum, 85-gallon drum, 100-gallon drum, standard waste box (SWB), or ten drum overpack (TDOP)), as prepared for shipment in a TRUPACT-II package, is limited such that the exterior radiation field, both gamma and neutron, shall be less than 200 millirem per hour (mrem/hr) at the package surface. This dose rate limit is for payload containers prior to addition of any lead, steel, or other shielding material to the payload containers for *as-low-as-reasonably-achievable* (ALARA) dose remediation purposes during non-transportation handling operations.

The TRUPACT-II package is not designed to provide significant gamma or neutron shielding. Three shells, the inner containment vessel (ICV), the outer containment vessel (OCV), and outer containment assembly (OCA) outer shell are composed of stainless steel having minimum thickness of ¼ inch, $^{3}/_{16}$ inch, and ¼ inch, respectively. Approximately 10 inches of polyurethane foam occupies the annular cavity between the OCV and OCA outer shell.

Prior to transport, the TRUPACT-II package shall be monitored on the semi-trailer or railcar for both gamma and neutron radiation to demonstrate compliance with 10 CFR §71.47. Since the TRUPACT-II package is not significantly deformed under NCT, the package will meet the dose rate requirements for NCT if the measurements demonstrate compliance with the allowable dose rate level in 10 CFR §71.47. The shielding transport index, as defined in 49 CFR §71.4, will be determined by measuring the dose rate a distance of one meter from the package surface per the requirements of 49 CFR with 49 CFR §173.403.

Shielding materials are not specifically provided by the TRUPACT-II packaging, and none are permitted in the payload containers to meet the dose rate limits of 10 CFR §71.47 for NCT. Therefore, shielding provided by the stainless steel shells and polyurethane foam of the package is not needed to meet the higher dose rate limits after HAC tests delineated in 10 CFR §71.73. This ensures that the post-HAC, allowable dose rate of one rem per hour (rem/hr) a distance of one meter from the package surface per 10 CFR §71.51(a)(2) will be met.

Even if payload material is released from a payload container during a HAC event, the post-HAC dose rate limit of one rem/hr at one meter from the package surface will always be met. This is because each CH-TRU waste payload container must have a dose rate less than 200 mrem/hr on contact prior to the addition of any ALARA dose reduction shielding for non-transport handling operations prior to being loaded into the TRPACT-II package. Since shielding within the payload containers is not permitted to meet the transportation dose rate limits for NCT, release of the materials from the payload containers during a HAC event will not increase the dose rate significantly or cause it to exceed the dose rate limits for the HAC.

9975 Package (high impurity Pu/U Metal and Oxide Contents)

The Model 9975 package was justified [Ref. 9] and authorized to ship solid plutonium and uranium materials that had been processed to the DOE-STD-3013 standard in order to deinventory materials from former DOE sites to a consolidation location at the Savannah River Site. These materials were characterized by a bounding RAM inventory and the light element impurities that were known to be involved in the processing of these materials. Light elements, particularly beryllium, produce neutron radiation through (α, n) reactions with the RAM. While the bounding RAM and Be masses were established, the size distribution and mixing of the RAM and Be particles could not be defined nor controlled. A "worst case" shielding analysis with RAM and Be intermixed at the molecular level calculated dose rates 300 times the NCT limits. While dose rates this high had never been measured in these materials they were theoretically possible. The 9975 SARP [Ref. 9] documented the high dose rates but established a dose rate measurement methodology for package compliance with the regulatory limits.

5.1 Discussion and Results
For content envelopes C.3b and C.4, the analysis modeled no impurities within the contents. Modeling the maximum allowed quantity of impurities, homogeneously mixed, in content envelopes C.3b and C.4 results in the calculated dose rate exceeding the dose rate limits. Therefore, if the impurity content of content envelope C.3b or C.4 cannot be shown to be negligible, or the restrictions given in Appendix 5.8 cannot be met, *the measurement of dose rate at the surface of the package, as described in Appendix 5.1, shall be used to determine compliance with regulatory requirements for shipment*. These restrictions are severe, but assure that package dose rates will meet regulatory requirements for shipment.

7.2.3 Loading and Closing the Package

16. Perform and document a radiological survey of the closed drum. The survey measurements shall provide verification that the following specified limits are not exceeded:
    a. External radiation levels specified in 10 CFR 71.47, with the exception of packages with content envelope C.3, which shall meet the limits specified in Table 7.1.

9975 Package (^{233}U Metal/ Oxide Content)

An Addendum was written to the 9975 SARP [Ref. 10] that added a new Uranium Content Envelope that supports elevated concentrations of ^{233}U and ^{232}U materials with trace amounts of plutonium. The proposed content was not bounded by any of the previous content envelopes and a revision to the 9975 CoC was required. The new Content Envelope supported shipment of ^{233}U-bearing materials between various DOE Facilities. The new Content Envelope included an increase in the ^{232}U mass limit and a Shielded-Pig shipping configuration for the high ^{232}U content. Because of the low mass of ^{232}U (a maximum of 0.0101 grams in a 4,400 grams total RAM content) the Addendum permitted the increased ^{232}U based upon dose rate measurements. This authorization was agreed to and authorized in the Certificate of Compliance.

5.5.1 Discussion and Results
While ^{233}U is a concern for criticality (see Chapter 6), it does not pose a significant shielding concern. However, the production of ^{233}U often creates ^{232}U impurities in the material. The ^{232}U is a shielding concern due to its daughter product, ^{208}Tl, which emits a high energy gamma. The 9975 includes a nominal ½ inch of lead shielding. Addendum Reference 5.1 determined that 1.843E-3 gram of optimally decayed ^{232}U is allowed without additional

shielding. The allowed mass of ^{232}U has been reduced in this addendum to 1.8E-3 gram for conservatism. In addition, larger masses of ^{232}U can be shipped with additional shielding (i.e., a Shielded-Pig packaging configuration). Addendum Reference 5.2 examined a ^{233}U content (118 grams) with up to 0.0101 gram of ^{232}U. That amount of ^{232}U required additional lead shielding ($^{7}/_{8}$ inch of lead shielding at the side and $^{5}/_{8}$ inch of lead shielding at the top and bottom) to meet the dose rate shipping requirements.

1.2.3.1.5 Shielded-Pig Convenience Container
The Shielded-Pig packaging configuration is shown in Addendum Figure 2 *and is used when source material measurements* indicate that additional package shielding is required to meet regulatory package dose limits or added shielding for ALARA is desired.

9975 Certificate of Compliance, Revision 28 (January 2012)
(ix) For the contents described in 5(b)(ix) [Content Envelope C.9]:
- (c) If ≤ 0.0018 grams ^{232}U contents can be in Food-Pack Can. The food-pack can have a maximum of 100 g plastic. Aluminum pellets or foil for packaging is allowed.
- (d) *If > 0.0018 grams and ≤ 0.0101 grams ^{232}U or determined by dose-rate measurements the Shielded-Pig Convenience Container will be used.* The Shielded-Pig and aluminum convenience can manufactured per listed Addendum 2 drawing are required. PCV spacers replaced by Shielded-Pig honeycomb spacers manufactured per the listed Addendum 2 drawing.

Summary

10CFR §71.47 specifies the maximum allowed dose rate at a RAM package surface and in its vicinity based on the acceptable dose rates to which the public, workers, and the environment may be exposed. As such, the regulations specify dose rates, rather than quantity of radioactive isotopes and require monitoring to confirm the requirements are met. The package safety basis documentation (SARP) is required to demonstrate how the RAM package is designed and prepared for shipment to be in compliance with the CFR. While the NRC and DOE format and review guides specifically require demonstration and documentation of the package dose rates to be in compliance with the regulations, the NRC and DOE-EM have approved the systematic shipment of the packages with compliance to the regulatory dose rate limits determined by measurements.

References

1 *Packaging and Transportation of Radioactive Material*, Code of Federal Regulations, Title 10, Part 71, Washington, DC (December 2012).
2 DOE O 460.1C, *Packaging and Transportation Safety,* U.S. Department Of Energy Office of Environmental Management, (May 2010)
3 IAEA Safety Standards, *Regulations for the Safe Transport of Radioactive Material*, Safety Requirements, TS-R-1, (2005 Edition)
4 IAEA, Safety Standards Series, *Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material*, Safety Guide No. TS-G-1.1 (ST-2)
5 Regulatory Guide 7.9, Standard Format and Content of Part 71 Applications for Approval Of Packages For Radioactive Material, Revision 2 (March 2005)
6 NUREG-1609, Standard Review Plan for Transportation Packages for Radioactive Material, U.S. Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, (March 1999)
7 UCID-21218, Packaging Review Guide for Reviewing Safety Analysis Reports for Packagings, Revision 2, (October 1999)
8 TRUPACT-II Safety Analysis Report, Revision 20 (July 2004)
9 *Safety Analysis Report for Packaging, Model 9975*, S-SARP-G-00003, Revision 0 (January 2008)
10 *Justification for ^{233}U Content Envelope*, Safety Analysis Report for Packaging, Model 9975, Addendum 2, S-SARA-G-00002, Revision 1, (May 2008).