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CONSIDERING RADIOACTIVITY THRESHOLDS BASED ON SECURITY RISK

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Abstract

The IAEA Coordinated Research Project J02011 on Improving the Security of Radioactive Material throughout its Lifecycle, Associated Facilities, and Associated Activities includes as an objective verification of international guidance with respect to controlled radionuclides and activity level thresholds in order to determine if the safety thresholds are an appropriate basis for establishing security requirements and devising a new list of radionuclides and/or thresholds for security purposes, if appropriate. The existing IAEA category thresholds are based on so-called D-values or "dangerous quantities" of radionuclides. These D-values are determined using specific scenarios which could result in severe deterministic effects from direct exposure to a source or dispersion more typical of an accident scenario. This may not be appropriate for an adversary who may be considering alternative consequences. To address this objective, an evaluation of the D-values and consideration of an alternative threshold framework will be conducted.

1. INTRODUCTION

The *Code of Conduct on the Safety and Security of Radioactive Sources* (Code of Conduct) published by the International Atomic Energy Agency (IAEA) provides requirements for the safety and security of radioactive sources. This document includes an annex, *List of Sources Covered by the Code,* that includes a table of relevant radionuclides and radioactivity values corresponding to Categories 1, 2, and 3. Categories are defined as follows [1]:

- Category 1: likely to cause permanent injury to a person who handled them for more than a few minutes and probably fatal to be close to unshielded material for a few minutes to an hour
- Category 2: could cause permanent injury to a person who handled them for a short time–minutes to hours, possibly be fatal to be close to unshielded material for hours to days
- Category 3: could cause permanent injury to a person who handled them for some hours, possibly fatal to be close to unshielded material for days to weeks

Category values are tabulated for sixteen radionuclides plus an additional six with the caveat that the additional radionuclides are "very unlikely to be used in individual radioactive sources with activity levels that would place them within Categories 1, 2, or 3."

In 2003, the IAEA published the report *Categorization of radioactive sources*, IAEA-TECDOC-1191 that defined the concept of the "D" value, or *dangerous* value, that was used to define thresholds for the aforementioned categories. The D-value itself corresponds to the Category 3 threshold, the Category-2 threshold is 10 times the D-value, and the Category 1 value 1000 times the D-value. The D-values themselves are calculated

based on specific deterministic effects and exposure scenarios defined for accident scenarios [2]. This document also introduced the concept of A/D or the quotient of radioactivity and D-value. This allows for aggregation of different amounts of radioactivity and radionuclide types to determine if a varied radiation source inventory meets a higher category than the individual sources or radionuclides.

2. DANGEROUS VALUES (D-VALUES)

The D-value concept was further developed and expanded in *Dangerous quantities of radioactive material (D-values)* [3]. This document describes all of the parameters and calculations used to determine the D-values. Calculation of D-values generally can be described as follows:

1. Consider a set of deterministic effects.
2. Determine from literature threshold radioactivity values for each of those effects.
3. Using a set of scenarios, calculate amounts of radioactivity for each scenario that meet the threshold values.
4. Determine the D_1 threshold as the minimum radioactivity meeting the two source exposure scenarios.
5. Determine the D_2 threshold as the minimum radioactivity meeting the four dispersion exposure scenarios.
6. Determine the D-value as the minimum radioactivity threshold between D_1 and D_2.

The scenarios used in step 3 are as follows:

- Pocket: carrying an unshielded source resulting in localized damage to source tissue.
- Room: in the vicinity of an unshielded source for days to weeks.
- Inhalation: fire or explosion resulting in airborne exposure.
- Ingestion: leaking source resulting in ingestion or material placed in water supply (limiting of two scenarios).
- Contamination: skin contaminated from leaking source.
- Immersion: external exposure to red marrow from immersion in noble gas cloud.

The first two scenarios in this list are used to determine D_1 and the latter four used in D_2.

While D_1 and D_2 for each of the radionuclides in the Code of Conduct are published, the limiting scenarios are not. An effort was undertaken to recalculate each scenario value for the sixteen radionuclides published in the Code of Conduct. The D-values and limiting scenarios are provided in Table 1. Note that of the six scenarios, only inhalation and pocket are actually found limiting.

Table 1: Limiting Scenarios for D-values for Radionuclides Listed in the Code of Conduct.

Radionuclide	D-value (TBq)	Limiting Scenario
^{241}Am	0.06	Inhalation
^{241}Am/Be	0.06	Inhalation
^{252}Cf	0.02	Pocket
^{244}Cm	0.05	Inhalation
^{60}Co	0.03	Pocket
^{137}Cs	0.1	Pocket
^{153}Gd	1	Pocket
^{192}Ir	0.08	Pocket
^{147}Pm	40	Inhalation
^{238}Pu	0.06	Inhalation
^{238}Pu/Be	0.06	Inhalation
^{226}Ra	0.04	Pocket
^{75}Se	0.2	Pocket
^{90}Sr/^{90}Y	1	Pocket
^{170}Tm	20	Pocket
^{169}Yb	0.3	Pocket

While this system is likely appropriate when considering the safety aspects of radioactive sources, the scenarios, especially deterministic effects to the skin, may be more representative of accident type consequences than those resulting from theft or sabotage of sources.

3. COORDINATED RESEARCH PROJECT OBJECTIVES AND STATUS

A review of the methodology used in the D-value determination and the use of the Category system is occurring as a part of a current IAEA coordinated research project, *Improving the Security of Radioactive Material throughout its Lifecycle, Associated Facilities, and Associated Activities,* J02011.[1] The specific objectives of this project are to (paraphrased):

- Develop guidance or procedures to address gaps where radioactive material may fall out of regulatory control or protection is reduced.
- Identify strengths and weaknesses within existing security measures for fixed and mobile radiation source applications.
- Verify that international guidance in the Category system of thresholds provides an appropriate basis and, if not, devise new security-based thresholds and a new list of radionuclides if warranted.

The work described in this paper directly addresses the third item.

As is stated in the objective, the work in question will consist of one or two parts. The first is to "verify international guidance with respect to controlled radionuclides and activity level thresholds." As described in the objective, the project team is in the process of reviewing the process and parameters for determining D-values as to their applicability to security of sources. While a judgement on this has not yet been made, there is an obvious concern that the D-values and associated category thresholds address only deterministic effects and not associated stochastic effects including cancer risk from low-level exposures. Inclusion of cancer risk within the system may address consideration of economic effects of a theft and dispersion of material as well as associated harm.

If this determination indicates that a revision is necessary, the second part of the analysis will be to recommend changes to the system. Changes will likely be in consideration of a broader breadth of consequences to include those more relatable to security. Such consequences will likely include not only health effects as incorporated into the D-values, but also psychosocial and economic effects, leveraging studies from the Fukushima accident and other analyses on the economic impact of radioactive material dispersion [4].

REFERENCES

[1] Code of Conduct on the Safety and Security of Radioactive Sources, IAEA/CODEOC/2004, IAEA, Vienna (2004).
[2] Categorization of Radiation Sources IAEA-TECDOC-1344, IAEA, Vienna (2003).
[3] Dangerous Quantities of Radioactive Material (D-values), EPR-D-VALUES, IAEA, Vienna (2006).
[4] TROST, L., VARGAS, V., "In a New York Minute: Economic Impacts of Radiological Dispersion Device" International Conference on the Security of Radioactive Material, The Way forward for Prevention and Detection (Proc. Int. Conf. Vienna, 2018), International Atomic Energy Agency, Vienna, (2018).

[1] More information can be found at https://www.iaea.org/projects/crp/j02011.