WNTI Industry Task Force: Major Issues for Consideration for the Criticality Assessment of Fissile Waste Transport

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Summary

The World Nuclear Transport Institute (WNTI) has formed a Task Force in order to promote a greater degree of uniformity in the way criticality assessments are carried out for the transport of fissile materials. Part of the Task Force's remit is to consider the transport of fissile bearing wastes. The Working Group has identified a number of issues of potential concern for consignors of these materials. The purpose of this paper is to raise awareness of these issues; examples are given to illustrate the extent of the difficulties. Some ideas for solutions are suggested.

1. Introduction

WNTI

WNTI [1] was founded in 1998 by British Nuclear Fuels plc (BNFL) of the United Kingdom, COGEMA of France, and the Federation of Electric Power Companies (FEPC) of Japan to represent the collective interests of the radioactive materials transport sector and also those who rely on safe, effective and reliable transport. Over the past few years, WNTI has grown dramatically with member companies drawn from a wide range of industry sectors, including major utilities, fuel producers and fabricators, transport companies and package producers.

With its small secretariat staff, and drawing on a large pool of industry expertise from among its Members, WNTI is committed to ensuring that transport, essential to bringing the benefits of radioactive materials to where they are needed the world over is conducted safely, efficiently and reliably.

Task Force

In 2004, WNTI set up a Task Force to explore the feasibility of achieving greater industry standardisation in the methods and data used for transport criticality assessment. The work programme has been designed to:

- fully understand all of the methods used by industry in the preparation of transport criticality safety cases for fuel cycle and waste materials;
- determine the commonalities and also the differences in approach by applicants in preparing transport criticality safety cases and also by Competent Authorities in assessing them;
- identify ways in which these processes could be rationalised to reduce the effort and shorten the time involved.

Transport of Fissile Wastes

Part of the project is concerned with the transport of waste materials containing fissile species, mainly plutonium and uranium isotopes. Radioactive wastes containing fissile materials have always been produced as part of the nuclear fuel cycle. More fissile-bearing wastes will be produced as a result of the decommissioning activities which are currently going on around the world to dismantle ageing facilities. Eventually much of the waste is likely to require transportation across the public domain to a repository or other disposal site. The transport of wastes is likely to become a major interest for both nuclear businesses and regulators.

There are a wide range of fissile-bearing waste materials to deal with, examples including: metals, corroded magnesium/aluminium sludges, concrete from decommissioning projects and plutonium wastes containing PVC, polyethylene, steels and general trash. There are also "legacy" wastes; i.e. mainly operational wastes that have been lain untouched, sometimes for several decades.

Most of these wastes are classified as Intermediate Level Waste (ILW), some are Low Level Waste (LLW); very little will be classified as High Level Waste (HLW). There may be a considerable volume of waste needing transport. For example, in the UK, it is estimated that about 200,000 m^3 ILW may require transportation, and much of this will need a criticality assessment. With a standard UK waste transport package being able to accommodate about 1-2 m^3, of waste, this adds up to tens of thousands of package movements. Of course, worldwide the figures are considerably greater.

In pursuing these goals, the WNTI Task Force has identified a number of issues of direct concern to the consignors of fissile-bearing wastes. These are described in the remainder of the paper.

2. The Issues

Within Europe, the transport of radioactive materials is carried out in accordance with the IAEA Regulations [2,3]. The Regulations were first formulated many years ago, when the transport of primary fuel-cycle materials (e.g. uranium ores, fuel assemblies, fissile powders) were the principal concern. These materials can pose a high criticality risk because they are concentrated and unadulterated by dilutents and neutron poisons; in some circumstances a criticality could be achieved with small (kg) quantities of the fissile material.

In contrast, fissile waste usually presents a low criticality risk. Generally, the wastes are very different in nature from primary fuel-cycle materials for one or more of the following reasons:

- the mass of fissile material per package is small compared to the critical quantity;
- the concentrations of fissile material are very low;
- the waste matrix contains a large proportion of diluents and neutron absorbers.

These factors mean that, even under the most extreme circumstances, criticality is generally much less likely than with primary fuel-cycle materials. However, the characteristics of fissile waste can lead to difficulties in the following three areas:

- exceptions and exemptions in the IAEA Regulations;
- criticality modelling under the IAEA Regulations;
- compliance with the requirements of the IAEA Regulations;
- making the overall risks ALARP (ALARA).

The remainder of the paper explores these issues in greater depth, providing examples to illustrate difficulties.

3. Exceptions and Exemptions in the IAEA Regulations

Seemingly a natural assessment route for fissile waste, consignors often find it extremely difficult to employ these criteria in a useful way when dealing with waste materials. Currently, the criteria are essentially based on low fissile mass (< a few hundred grams), low fissile concentrations (< 5 g in any 10 litres) and very low uranium enrichments (< 1%) – Reference [2] has the details (see paragraph 672). Many waste streams fail to satisfy these criteria, whilst having demonstratively large safety margins in terms of K-effective.

In reality, many waste materials, because of the nature of the waste matrix itself, present negligible criticality risk. Examples of wastes with a negligible criticality risk include contaminated soil, concrete, metals and sludges.

In all of these cases, even though an individual transport package might contain kg quantities of fissile material, there would be no real criticality risk. The waste matrix dilutes the fissile material and also provides significant thermal neutron absorption.

It would be beneficial to waste consignors to have a wider range of exception and exemption criteria for use with wastes. Work is underway to extend the range of exceptions/exemptions (for example see [4, 5]) based on minimum fissile/absorber ratios and dilution factors, but some criticality experts consider a more flexible approach is needed.

One idea that has been suggested is the idea of "equivalent reactivity". A waste form could be excepted provided that it is no more reactive than uranium enriched to 1%, provided that the fissile material, diluents and absorber are essentially (neutronically) homogeneously inter-mixed and robust against credible accident conditions. It is acknowledged that some work would be required in gaining agreement as to what constitutes a credible accident condition.

Another idea is to include a general exception statement in paragraph 672 along the lines of "exceptions agreed with the Competent Authority". This would allow consignors/regulators to agree the appropriate exception criterion to deal with the waste-form, if appropriate.

4. Criticality Modelling Under the IAEA Regulations

The assessment philosophy inherent in the IAEA Regulations generally forces the criticality assessor to assume worst-case conditions in criticality modelling. Typically, the fissile and moderating materials are assumed to form a spherical geometry, in a ratio which maximises the neutron multiplication factor, with a lack of absorbers/diluents and with a close-fitting thick reflector.

This philosophy is entirely sensible for higher-risk materials, such as fissile powders and fuel pellets, but far less appropriate for many waste materials. For wastes, these assumptions can often be wholly unrealistic and may represent a triumph of academic considerations over practical ones. For example, in plutonium contaminated waste materials, it is difficult to imagine an accident that would form the waste into a configuration resembling a high-density moderated and reflected sphere. This kind of approach results in package fissile limits that can be very restrictive. Over pessimism is also to be avoided because it can lead directly to an increase in other types of risk, with very little benefit in terms of criticality safety. For example, overly pessimistic fissile limits can result in:

- package splitting with the creation of secondary wastes and increase in dose to operators;
- additional handling and transports and an increase in conventional (i.e. non-nuclear) hazards.

Clearly, a more pragmatic approach to criticality modelling of wastes would be beneficial. One idea would be to allow criticality assessors to define and justify their own criticality models, which would be appropriate to the waste-form, subject of course, to regulatory approval. For example it may be more appropriate for an assessor to assume a uniform, infinite mixture rather than a sphere or to take account of the range of materials present in the waste rather than assume moderation/reflection by the most onerous.

5. Compliance with the Requirements of the IAEA Regulations

It is a requirement under the IAEA Regulations that the Consignor must be able to demonstrate compliance with package fissile limits and exception/exemption criteria. Waste materials can create difficulties for compliance in two areas:

- fissile monitors;
- waste characteristics.

Fissile monitoring (both gamma and neutron)

The most obvious method of demonstrating compliance with transport criticality limits is by fissile assay using radiation detection. Worldwide, low and high resolution gamma spectroscopy and neutron coincidence counting are the most commonly used assay techniques.

However, for some waste streams, particularly "legacy wastes" containing an often poorly characterised range of materials, there can be great difficulties in establishing an accurate fissile value by recording neutron and gamma radiation. There can be many reasons why assay becomes inaccurate, but the main difficulties arise from:

- **Self-shielding in lumped fissile materials:** Here, radiation from the interior of the fissile material (e.g. fuel pellets) can be absorbed in the exterior layer. The net effect is that the assay machine cannot "see" all of the fissile material and an under-estimate of results.
- **Shielding by waste materials:** Some wastes may contain effective radiation shields (e.g. steelwork or lead blocks for gamma, Jabroc for neutron). An under-estimate can also result.
- **Contamination by non-fissile species:** Gamma spectroscopy works by counting photons at an energy characteristic of the fissile nuclide. Any contamination of the waste by nuclides emitting at a similar energy will result in an over-estimate of the fissile mass. Often, if it is known that these nuclides can be present, compensatory measures are introduced which can lead to under-estimates for the majority of the wastes.
- **The distribution of fissile material:** The factor for converting radiation counts per second into grams fissile depends on assumptions made on the physical distribution of the fissile material. Often, the fissile distribution cannot be known and the pessimistic assumption of a point source is made.

Safety factors can be derived to ensure that an under-estimate of the fissile material cannot occur, but often this will be highly penalising for the majority of the waste packages. Experience has shown that the safety margins in the final assay values for waste packages can be very large.

Waste Characteristics

More generous fissile limits may sometimes be obtained by taking account of specific characteristics of the waste. For example, credit could be taken for neutron absorbers or diluents in the matrix. Or, as another example, by basing the assessment on a uniform distribution of fissile material throughout the package.

For mixed waste-forms, such as Plutonium Contaminated Waste Materials or Contaminated Metals, the question arises as how to demonstrate compliance with the assumptions made in the criticality assessment. Clearly, in a large waste stream it is impracticable to sample every package. Indeed for large packages, it can be difficult to ensure that a sample is representative of the package as a whole.

In other industries, statistical methods are routinely used for situations such as these. The general approach would be to produce a sampling plan (i.e. % of waste stream to be sampled and how to sample) based on a confidence level and the inherent variability of waste. However, there is no guidance as to an appropriate approach in the IAEA documentation. In the author's view, this is an area which is ripe for development and would benefit from discussion with Competent Authorities.

6. Examples

Two examples are presented. The first illustrates how the IAEA Regulations result in a small fissile limit for a waste package and a much larger one for a PuO_2 powder package, even though criticality would be much easier to achieve with PuO_2 powder. The second example shows some of the difficulties in dealing with waste material. The examples are based very firmly on real packages which are in use today.

Example 1 – PCM and PuO_2 Transport Packages

Table 1 below compares two Type B Transport Packages: Package 1 for plutonium contaminated waste materials (PCM) and Package 2 for PuO_2 *powders. Both have been licensed by Competent Authorities.*

Type B Package	Package 1	Package 2
Fissile material	Pu or U as PCM	Pu as PuO_2 $\geq$ 17 w/o Pu240 in Pu $\leq\leq 4$ g(PuO_2) cm^{-3}
Other materials	May contain any material with a hydrogen density less than or equal to water (hydrogen density = 0.11 $g.cm^{-3}$). No material providing greater reflection or moderation than water.	None except intrinsic moisture $\leq$ 3.2 w/o
Criticality Model	Fully reflected and optimally moderated sphere. No absorbers or diluents.	PuO_2 confined to canisters within accurate model of the SAFKEG
Maximum fissile material	374g Pu or 620g U235.	18kg PuO_2.

Table 1: Comparison of Type B Transport Packages

Package 1 has been licensed for a range of wastes, but for simplicity only one limit has been shown. The other fissile limits are of similar magnitude.

It can be seen that the fissile limits are very different: hundreds of grams for the Package 1 and tens of kilograms for Package 2. The reason for this is that the PuO_2 powder is confined to limited-volume canisters within Package 2, whereas the Pu (in theory) is free to assume any geometry within Package 1, which is physically large (m^3). Also the PuO_2 powder is well characterised in terms of moderator content, whereas the waste is not.

The IAEA Regulations do not permit any consideration of risk; therefore in Package 1 the incredible accident scenario of all of the fissile material and moderator coming together in the waste as an optimally moderated sphere must be considered. This leads to a very small fissile limit for Package 1.

Yet, if asked, most criticality assessors would rate the PuO_2 powder as carrying a far greater criticality risk than PCM.

Example 2 – Heavy Drums

In the UK, LLW is sent to the Low Level Waste Repository (LLWR), situated near the village of Drigg in Cumbria for long term disposal. Also on the site are the remaining few drums of plutonium contaminated waste materials (PCM) from the early days of the UK's nuclear development programme. There was originally a large stock of these drums, but LLWR have removed the vast majority. However, there remain about 130 x "heavy" 200 litre PCM drums.

The drums contain mostly concrete – the weight of each drum ranges from about 170 kg to 270 kg. This mass of concrete makes assay with conventional gamma and neutron techniques extremely difficult. The attenuation and scatter provided by the concrete means that, even with sophisticated measurement techniques and long counting times, it will be impossible to obtain an accurate assay value for most of the drums using standard assay techniques.

This creates a difficulty: to fully meet the IAEA Regulations a conservative fissile value is required. An upper bound can usually be derived, yet this is likely to exceed the few hundred grams of fissile material permitted in the transport container. Some of the options being considered include: more sophisticated (and expensive!) assay techniques and drum splitting or repackaging.

Yet the drums pose a negligible criticality hazard. This shows that the IAEA Regulations can force the consignor to go to extreme lengths for no real safety benefit.

7. Discussion and Conclusions

As described above, for fissile wastes, there can be difficulties in rigorously meeting the IAEA Regulations in terms of criticality assessment and compliance.

The easiest way to meet the Regulations is to adopt a highly conservative approach in all respects; however, in doing so there is often a very real danger of deriving fissile limits which are overly conservative and of limited practical use.

If this resulted only in extra cost, it would not be so bad. However, there are occasions when rigorously following the Regulations would reduce safety. The problem with over-conservatism in criticality assessment is that can lead to increases in other risks:

- repackaging of wastes to achieve a smaller fissile mass –
  - operator exposure to radiation, hazardous chemicals etc;
  - more handling, more potential for accidents;
  - more storage requirements.
- hazardous operations, e.g. concrete breaking in an air suit, sorting through wastes;
- dilution of wastes to achieve a smaller fissile mass – creation of additional wastes;
- more package transports and an increase in conventional risks.

Clearly for fissile wastes, trying to meet the IAEA Regulations in all respects in respect of criticality safety may lead to packaging solutions which are non-optimum in terms of safety.

This paper proposes that work should be undertaken to deal with the three areas of concern, specifically:

I. **Exceptions/exemptions:** The existing criteria need to be extended to except/exempt highly poisoned and diluted wastes. This could be accomplished by either defining new criteria for specific materials (e.g. g Pu per tonne of soil), or preferably by defining a methodology for generating such criteria. (One means may be the development of idea of “equivalent reactivity” in Section 3). Another idea is to include a general exception statement in paragraph 672 along the lines of “exceptions agreed with the Competent Authority”.

II. **Criticality modelling:** Guidance for criticality assessors and regulators is needed to allow them to define criticality models appropriate to the waste-form. Firstly, this needs agreement on appropriate accident conditions so as to take account of the behaviour of the waste-form during an accident. For example, a homogeneous mixture of fissile material in the waste would be an appropriate model, provided that it could be shown that the fissile material/waste is neutronically uniform (or bounded by that assumption) and that the assumption is robust against fire, water and credible variations in the waste.

III. **Compliance:** Given the huge volumes of fissile wastes that will be dealt with and the difficulties in assay by radiation, completely reliable and accurate assay is not credible. It follows that guidance is needed on appropriate levels of accuracy and reliability and acceptable sampling strategies to support this.

References

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