

WNTI Industry Task Force on the Harmonisation of Transport Criticality Assessments

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Summary

For the international transport of fissile materials, a single design of transport package will be scrutinised by more than one Competent Authority. This may require multiple criticality analyses to obtain base approval and foreign validations. When several competent authorities are involved, the resolution of these issues can be very time consuming and expensive. Furthermore, the implementation of the IAEA Transport Regulations may not be uniform.

The World Nuclear Transport Institute (WNTI) has formed a Task Force in order to promote a greater degree of uniformity in the way transport criticality assessments are carried out by Industry. It is intended that methodologies, data and technical advice that is accepted by the Task Force as representing best-practice will be recorded in a "Criticality Knowledge Base", which will be freely available to WNTI Members.

This paper fully explains the issues, outlines the work programme initiated by WNTI and describes progress to date. Areas needing further consideration are described.

Introduction

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, package producers, etc.

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.

WNTI, together with criticality experts from its member organisations, is currently embarked on a major project to explore the possibility of defining an industry-wide set of methodologies and data to assist in the assessment of transport criticality. This is referred to as the "Criticality Knowledge Base". Work is underway to identify opportunities for standardisation in the way that criticality assessments are made in applications to Competent Authorities.

Although there is a single set of regulations governing the transport of radioactive materials (the IAEA Regulations [2, 3]), there can be major differences in the way criticality assessors and regulators make assumptions and use models. This leads to inconsistency between international assessments and sometimes an excess of pessimism.

The remainder of this paper more fully explains the background to this project, the extent of the similarities and differences in criticality methodologies, associated issues such as Intellectual Property Rights (IPR) and progress to date.

The Need for Harmonisation of Transport Criticality Assessments

Within Europe, the national and international transport of radioactive materials is carried out in accordance with the IAEA Regulations [2, 3]. These are a set of rules and regulations which provide safety standards for transport in the public domain of packages containing radioactive materials. The IAEA Regulations have been agreed internationally and provide a very high standard of safety so much so that there has never been a criticality accident involving a certificated transport package.

Conference paper

With regard to criticality safety modelling, the IAEA Regulations require the assessment of a fissile transport package under both normal and accident conditions of transport. The accident conditions of transport are very challenging and include: water immersion, highly energetic impacts onto unyielding surfaces and the effects of prolonged and very hot fire.

In practice, accident modelling generally depends upon the analyst making a credible set of assumptions (e.g. on the degree of fuel break-up, pin displacement). Of necessity, these can be highly subjective because of the lack of test data to adequately describe the performance of a package and its contents under accident conditions. It is the subjectivity which can lead to difficulties.

For example, in assessing impacts involving transport packages carrying fuel pins, because of budgetary and time constraints, it is practically impossible to completely describe the state of the fuel assemblies after the accident in a form which would allow highly accurate criticality modelling. There are so many fuel pins, each with its own 3-D damage state that it is also impracticable to accurately represent the damaged fuel in a Monte-Carlo criticality model. What often happens is that the greatest pin displacement from a highly idealised, but limited, test on a similar fuel assembly would be applied to all fuel pins in the package, together with highly pessimistic representations of the fuel debris and moderation state. In most cases this requires a degree of interpretation of the experimental results, with large safety factors being applied to allow for uncertainties. This is one example of many.

It can be appreciated that this state of affairs encourages different approaches to modelling an accident-state. There is a tendency to construct hypothetical models of accident-states, some of which, although bounding or conservative, have an unduly large reactivity (Keff). Criticality evaluations, of potentially identical situations, can then lead to radically different conclusions depending upon the assessors conducting the study. In the past, this has led to transport assessments collecting conflicting and inconsistent reviews from Competent Authorities, with the final submission being based on the “worst of all worlds”.

WNTI Task Force

In 2004, in order to improve matters, 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 criticality safety cases for fuel cycle materials;
- determine the commonalities and also the differences in approach by applicants in preparing 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.

Information has been elicited in a series of work-shops. WNTI members were first asked to describe the base assumptions/methods/data of the criticality safety cases, for both normal and accident conditions of transports, in their applications to competent authorities. The responses were then analysed to identify where the safety cases showed consistencies and also where there were differences.

Transport criticality safety assessments are complicated and so there were many factors to consider, such as:

- enrichment maps;
- dimensional tolerances;
- lattice expansion;
- fuel break up and dispersion;
- confinement system;
- water ingress and differential flooding;
- safety criteria for arrays of packages;
- integrity of water channels within the assembly and fuel assembly shroud;
- credit for burn up;
- boron loading;
- parametric analysis on water density;
- deformation of basket;
- radial displacement of fuel assemblies;
- credit for shock absorbers or resin.

At the start of the project, it was expected that differences in approach would be mainly limited to accident conditions and that a high level of consistency would be seen for analysis of normal conditions of transport. The review highlighted that this was not necessarily the case as significant differences were also found in the representation of:

- pellet density;
- pellet diameter;
- fuel pin diameter;
- fuel pin cladding thickness;
- Pellet/clad gap;
- fuel pin pitch;
- fuel active length;
- position of fuel active length above the base of the fuel assembly;
- fuel assembly overall length;
- assembly array size;
- location of missing pins / water tubes / guide tubes.

All fuels are subject to manufacturing tolerances, and these need to be incorporated into the analysis in a conservative manner for both fresh and unirradiated fuel assemblies. In some of the examples reviewed, however, the assumed conditions were of such a pessimistic nature that the true sub-critical margins were not visible. For this reason the Task Force agreed to increase the scope to consider base case conditions.

Criticality Knowledge Base – Aims and Scope

It is obvious that a completely standardised approach would not be feasible because of differences in fuel, flasks and regulators. However WNTI believes that a great deal of standardisation can be achieved based on a set of suitable and consistent methods, data and assumptions. The benefits are considered to be in the areas of:

- harmonisation of assessments;
- sharing of knowledge and methods;
- education and training;
- provision of detailed guidance to assessors;
- minimisation of unnecessary pessimism.

The WNTI subgroup is structuring the Criticality Knowledge Base to function as a basic resource for transport criticality assessors and therefore other technical areas (e.g. shielding, stress) are outside the scope of the project. The specific aims are to provide:

- a single agreed source of information for criticality assessors;
- guidance to assessors on which accident-states to assess;
- guidance to assessors on how the accident-state may be assessed;
- an explanation of the issues surrounding each accident-state;
- where possible, a list of all the relevant sources of data (indicating where none exist).

The Knowledge Base is not intended to be prescriptive. In other words, assessors will be able to exercise discretion and use the information (or not) as appropriate.

References

1. World Nuclear Transport Institute, Remo House, 310-312 Regent Street, London, W1B 3AX, <http://www.wnti.co.uk>
2. IAEA Safety Standards Series, TS-R-1, Regulations for the Safe Transport of Radioactive Material 1996 edition (as amended 2003).
3. IAEA Safety Standards Series, TS-G-1.1 (ST-2), Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material

Intellectual Property Rights

The utility of the Knowledge Base would be greatly enhanced by Members freely making available any information relating to transport criticality tests and methods of assessment. However, much of this information – tests, experiments, methodologies, etc – can be expensive to generate in the first instance and members may not wish to make data/methodologies freely available to all.

WNTI recognises the importance of protecting the IPR of contributing organisations. At the owner's discretion, the existence of some commercially sensitive information may be revealed in the Knowledge Base; however the information itself may only be available by direct negotiation with the owner; for example, by purchase, or information exchange.

Examples of Knowledge Base

Figure 1 shows the basic layout of the Knowledge Base. Examples are provided in Tables 1 and 2, at the end of this presentation, for the following fault-states:

- unirradiated and irradiated LWR fuel – Axial Impact – change in lattice pitch;
- irradiated LWR fuel – Axial Impact – cladding failures in irradiated fuel.

Knowledge Base Next Steps

Currently, the work is focused on LWR fresh and irradiated fuel in Type B transport packages. Table 3 gives examples of the major fault states that will be included in the Knowledge Base.

Currently, the work is focused on LWR fresh and irradiated fuel in Type B transport packages.

In the next stage of the work, the Knowledge Base will be extended to include the fissile/ISO and other packages (e.g. Pu package). It is intended that eventually the Knowledge Base will provide methodologies, data and advice for the transport criticality assessment of all types of package and fissile materials.

<div style="border: 1px solid black; padding: 5px; display: inline-block;">Unique reference for fault and failure modes</div>				
A2	Fault title. Full description of fault and how it can lead to an increase in K-effective. List of associated faults, conditions and issues.			
	Accident Condition/ Fuel Failure Mode	Supporting Information		Remarks and Additional Information
		Public Domain	IPR	
A2.1	Failure Mode 1	Reference X provides data for xyz fuel	Reference I provides data for xyz fuel	
A2.2	Failure Mode 2		
A2.3	Failure Mode 3		
<div style="display: flex; justify-content: space-between; margin-top: 20px;"> <div style="border: 1px solid black; padding: 5px; width: 30%;"> Readily available information – e.g. conference or journal papers, free reports. </div> <div style="border: 1px solid black; padding: 5px; width: 35%;"> Commercial information available – Knowledge Base provides only a brief summary. Assessor would need to contact author and pay for further information. </div> <div style="border: 1px solid black; padding: 5px; width: 30%;"> Technical information / advice for the criticality analyst. </div> </div>				

Figure 1: Layout of the Knowledge Base

A1	<p>Depending on package and fuel impact parameters:</p> <ul style="list-style-type: none"> • An axial impact has the potential to change the spacing between individual fuel pins. • For some fuels, this could lead to an increase in the neutron multiplication factor because light water reactor fuel elements are generally under moderated. 			
	Accident Condition/ Fuel Failure Mode	Supporting Information		Remarks and Additional Information
		Public Domain	IPR	
A1.1	No change in lattice pitch.	Reference A provides data/justification for XYZ fuel/package.	<p>Reference B provides data for XYZ fuel/package.</p> <p>Reference C provides data for XYZ fuel/package.</p> <p>NB Reference B, C etc could include such as FIP, tests/experiments with TN, FS 69 type packages.</p>	Criticality analysis of this particular accident condition would not be required in support of the Application, provided that the Reference data justifies no adverse change in lattice pitch.
A1.2	Increase in pitch over entire length of fuel assembly.	Not required.	Not required.	No justification required because this is the most conservative assumption for criticality analysis.
A1.3	Increase in pitch over single inter-grid.	Reference D for *** fuel.	No data available.	Reference data would be needed to provide the necessary justification. (The Knowledge Base should say where no data are available).
A1.4	Increase in pitch over limited length over several inter-grids.	Reference E for *** fuel.	Reference C for *** fuel.	Reference data would need to provide the necessary justification.

XYZ, A, B etc. are hypothetical (i.e. for the purpose of illustration)

Table I: Axial Impact: Change in Lattice Pitch in LWR Fuels

A2

Depending on package and fuel impact parameters:

- There are a number of ways in which fuel cladding may fail in an impact.
- Cladding failures could lead to unconstrained fuel debris or fuel pellets accumulating in the package.
- The important parameter for criticality assessment is the quantity of fuel released as pellets or as debris.
- Potential failure modes include:
 - rupture of pins caused by impact with end fittings;
 - fuel elements birdcage (bow) and rupture;
 - pins rupture while passing around the end fittings;
 - the spacer grids rupture pins;
 - deformation of the pins and the top/bottom fitting leading to rupture.

	Accident Condition/ Fuel Failure Mode	Supporting Information		Remarks and Additional Information
		Public Domain	IPR	
A2.1	No failure of cladding	Reference X provides data for *** fuel.	Reference Y provides data for *** fuel.	Criticality analysis of this particular accident condition would not be required, in support of the Application, provided that the Reference data on package and/or fuel justifies no failure of cladding and/or no loss of fuel.
A2.2	Complete failure of cladding (potential 100% release of fuel)	Not required.	Not required.	Release of all fuel from rods. No justification required because this is the most conservative assumption.
A2.3	Partial failure <1.0% of fuel released as debris	Reference Z for *** fuels.	FIP (possible example)	Package/fuel specific data required to support assumptions in criticality analysis.
A2.4	Etc.			

XYZ, A, B etc. are hypothetical (i.e. for the purpose of illustration)

Table 2: Axial Impact: Cladding Failures in Irradiated Fuel

Item	Damage	Consequence
AXIAL IMPACTS		
A.1	Pins slip axially.	Pins slide to region below or above poison plates, and/or to more optimum pitch arrangement.
A.2	Rupture of pins caused by impact with end fittings.	Possible release of fissile material. Release could be at the end plugs.
A.3	Penetration of the end fittings by the fuel pins.	Pins slide to more optimum pitch arrangement (possibly through the water circulation holes in PWR end fittings).
A.4	Pins pass around the end fittings.	Pins slide to more optimum pitch arrangement/into an unpoisoned region.
A.5	Pins rupture while passing around the end fittings.	Pins slide to more optimum pitch arrangement, possible release of fissile material.
A.6	The spacer grids rupture pins.	Possible release of fissile material.
A.7	Deformation of the pins and the top/bottom fitting leading to rupture.	Deformation of pin array, possible release of fissile material.
HORIZONTAL IMPACTS		
H.1	Lateral movement of the BWR assembly top/bottom fitting relative to the fuel pins causes shear at the pin/end fitting interface.	Possible release of fissile material due to shear at the pin/end fitting interfaces- occurs only for BWR fuels.
H.2	Shear and bending interaction between the pins and the spacer grids.	Possible release of fissile material.
H.3	Interaction between pins or between the pins and the lodgement wall.	Possible release of fissile material.
H.4	Interaction between the fuel pin end plug and the lodgement walls.	Possible release of fissile material.

Table 3: Principle Accidents States to be Included in the Knowledge Base for LWR Packages

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