

Hypothetical Accident Conditions – How can the underlying assumptions be rationalised for the purpose of criticality safety assessments?

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1. Introduction

It is acknowledged that criticality is a complex and often counter-intuitive science. It is also acknowledged that criticality safety analysis should contain a level of pessimism that ensures that minor variations in routine and normal conditions can not adversely affect nuclear safety. Generally, this is a manageable challenge, as, during normal conditions, the geometrical arrangement and state of the material has traditionally been considered to be well characterised, essentially it is assumed to remain in its 'as-loaded' and 'as designed' configuration.

The challenge arises when considering hypothetical accident conditions of transport when the underlying assumptions can differ widely from application to application and are often unrealistic and unachievable. A "credible" set of assumptions is subjective and depends on individual judgement. There is always opportunity to construct some hypothetical onerous scenarios that would create a higher reactivity. Criticality evaluations, of potentially identical situations, can then lead to radically different conclusions depending upon the entity conducting the study.

For international transports a single design may require multiple criticality analyses to obtain base approval and foreign validations. This situation has an important bearing on transport activities. When several competent authorities are involved, the resolution of these issues to validate a package can be time consuming and expensive and the implementation of the regulations may not be uniform.

From the operational point of view the inclusion of layer upon layer of contingencies

can lead to scenarios which are unnecessarily restrictive. This can restrict payload. This is important in all fissile nuclear material transports but particularly so in transport and storage strategies, for example for spent nuclear fuel, where payload can have a crucial effect on viability.

The characteristics of the fissile nuclear fuel cycle materials transported by the various countries have much in common and so have the designs of the packages to contain them. If underlying assumptions made in the criticality safety case could be rationalised, with the objective of achieving a greater degree of standardisation, then this should allow criticality safety to be assessed consistently and efficiently.

Fuel cycle materials can be considered in four main categories, namely fuel assemblies, both new fuel and spent fuel, oxide powder, granules and pellets, uranium hexafluoride and fissile wastes. Standardisation/rationalisation across the whole range of materials would be an ideal, but extremely challenging goal, with resource requirements commensurate with the magnitude of the goal.

A WNTI industry-led task force has been established to explore the possibilities of a standardised approach to criticality assessment. It is intended to consider the full range of fuel cycle materials eventually but work has been concentrated mainly on new and spent fuel assemblies initially since these are important in terms of the difficulties they present in criticality assessment. This is the main focus of this paper but the transport of fissile wastes, which is a growing area of importance, particularly from decommissioning activities, is also addressed in brief.

2. Criticality safety assessment – a way forward

In order to transport and store nuclear fuel assemblies safely it is necessary to maintain the fuel in a sub-critical arrangement, not only during normal but also under hypothetical accident conditions, and criticality safety cases for packages containing new and spent fuel assemblies have to cover all these situations.

During normal conditions, the geometrical arrangement and state of the fuel is well understood; essentially it is assumed to remain in its ‘as-loaded’ and ‘as designed’ configuration. This would suggest that one would see little variation in assumed "base case" conditions, irrespective of the entity completing the analysis.

However, in the event of a serious accident, the disposition and integrity of the fuel assembly may not necessarily be maintained and, depending upon the particular packaging design, it may be necessary to consider the fuel assemblies in a variety of states after an accident involving a severe impact. Changes in geometry could cause an increase in the reactivity of the fissile material giving rise to a potential criticality hazard.

In these circumstances the issue then becomes one of how credible is the scenario and how the consequential effects are mitigated by the other pessimism already assumed in the analysis.

It is therefore important to consider the issue of fuel integrity under impact accident conditions as it relates to fuel assemblies; then, to seek rational assumptions about the configurations and potential damage of a fuel assembly in a transport package that could arise from a 9m drop onto an unyielding target, a test which covers all accidents which can be realistically envisaged.

This is the area that *appears* to give rise to the most significant differences in the bases for criticality safety cases and their assessment. This is therefore one area where rationalisation could be beneficial.

WNTI set up a Task Force in 2004 to explore to what extent the objective of achieving a greater degree of industry

standardisation could be achieved. The work has been designed to:

- identify the various bases 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.

WNTI members were first asked to describe the bases 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 these safety cases showed consistencies and also where there were differences.

There are many factors to consider, such as enrichment maps, dimensional tolerances, the characteristics of neutron poisons, moderation states and water ingress. Commonalities and differences in approach in the preparation of safety cases can be found in all of these areas.

A Workshop was then convened to study the outcome of this analysis in order to determine the extent to which standardisation of approach in preparing criticality safety cases for new and spent fuel assemblies might be possible. The objective was to explore the possibility of agreeing a concept and format for a WNTI Industry Guide for New and Spent Fuel Assemblies.

2.1 Responses on criticality assessments for fuel assemblies

The responses from the WNTI members covered new and spent uranium and MOX fuel as summarised in the following table.

Source	Spent U fuel	Spent MOX fuel	New U fuel	New MOX fuel
Cogema Logistics	PWR & BWR	PWR	BWR	PWR & BWR
BNFL	BWR			
NFT	PWR & BWR			
NFI			PWR & BWR	
Framatome ANP			PWR	
Westinghouse USA			PWR	
NCS	PWR & BWR			

Analysis was carried out which highlighted areas where there is a common basis and also where there are significant differences in approach in the preparation of criticality safety cases for both new and spent fuel assemblies. Areas considered included:

- enrichment maps;
- lattice expansion;
- fuel break-up and dispersion;
- confinement system;
- water ingress and differential flooding;
- safety criterion for arrays;
- integrity of water channel 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 this review 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, variances being identified for:

- 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.

Sub-Groups were set up at the workshop to further study the scope for rationalisation in the three priority areas, (i) enrichment mapping/burn-up, (ii) fuel break-up/lattice expansion and (iii) water ingress with work to be carried forward to a second workshop to be convened in early autumn.

3. Proposed concept for a WNTI industry guide on criticality assessment methodology for spent and new fuel assemblies

Experience suggests that there could be an opportunity to rationalise the methodology in some important areas, which could reduce the effort, shorten the time and reduce the cost involved in obtaining approvals.

The objective of a WNTI Industry Guide would be to provide a philosophy and source of technical data (assumptions) to assist applicants in the preparation of safety cases for the transport of new and spent fuel assemblies with a view to achieving worthwhile rationalisation.

It would address "base case" conditions; for example, manufacturing tolerances and how these may be incorporated into analysis in a justifiably conservative manner. It would address major issues, including control of hazards following an impact accident, acknowledging that there are many ways that a criticality hazard can be controlled in the unlikely event that a transport container suffers a severe impact, such as being dropped or in a high speed crash.

For a given licence application a number of options may be considered to arrive at an acceptable solution and some of these may not be viable. However, there will always be different ways in which the requirements could be satisfied and it would remain the choice of the applicant which to adopt on the basis of cost/benefit considerations.

The cost of implementing a particular strategy, including the cost of analysis, design and manufacture of a package, the cost and time involved in obtaining approvals, together with maintenance and operational costs has to be compared with the corresponding benefits, of which payload is an important factor.

The proposed industry guide is not intended to offer advice on the optimum strategy or on design solutions to meet particular regulatory requirements because this will depend on the circumstances relating to a particular application. However, where possible, guidance would be included on sound generic engineering principles.

4. Future programme for the criticality assessment task force

4.1 WNTI Guidance Document for Fuel Assemblies

Discussion on a possible future programme that might lead to an Industry Guidance Document has identified the following stages that would need further consideration.

- (i) Preparation of the concept, format and content of the Guide.
- (ii) Working up of this to include more explanatory material and detail.
- (iii) Commercial/implementation considerations.

The timescale and resources to complete this work need to be considered.

4.2 Work on other fuel cycle materials

It is also intended to initiate work on other fissile fuel cycle materials. Initially oxide powder, granule and pellet packages will be considered and then fissile waste packages and uranium hexafluoride containers. A number of examples of criticality safety methodologies for each have already exposed significant variances.

4.3 The packaging and transport of fissile and fissile exempted wastes

With the ageing of nuclear installations, the need to transport large volumes of waste gives rise to further criticality safety challenges. Generally such waste will contain low concentrations of solid fissile material. The challenge is to determine the ratio between the solid non-fissile mass and the solid fissile mass that ensures sub-criticality in a commercially viable volume of material. The concern is that often the waste form is viewed and assessed as a highly reactive un-poisoned process material, i.e. similar to plutonium powder, rather than the waste that it actually is. The challenge is to provide 100% proof of the waste form or assume worst case ultimately leading to excessive numbers of transports with associated safety risks.

This is a complex and topical issue resulting in many proposed changes to the IAEA Radioactive Material Transport Regulations in the current Regulatory Review programme.

The WNTI task force has, so far, only considered a very small number of criticality safety assessments of waste and waste containers described by the US, UK and France. Initial indications are that assessment philosophy is fairly consistent albeit very conservative. Due to a lack of data on the waste drums or boxes and their

behaviour in a transport accident condition it was generally considered that all material escaped and accumulated. It was further assumed that the fissile material separated from the non-fissile to form an optimally moderated sphere, reflected by a conservative moderating matrix.

In practice, the concentration of fissile material in wastes is normally low but its distribution is not very well defined. As in the case of fuel assemblies, it is important in criticality assessments that whereas the assumed scenarios should err on the side of caution they should also be realistic. One way to achieve this is for applicants to provide the criticality assessor with rigorous evidence of the low risk nature of the waste. This will enable firm conclusions to be drawn with regard to the neutron moderating and reflecting abilities of the waste constituents, which can be included in the criticality model.

It is generally recognised that full criticality safety assessment for the transport of these types of materials is onerous and not commensurate with the risk of criticality. It is therefore timely to consider the issue of fissile content of low-level waste and to provide solutions to issues arising from the fissile exception clauses within the Transport Regulations. A fundamental component of such a study would be the determination of rational assumptions about configurations possible after accidents, which can be realistically envisaged.

To achieve this would require co-ordinated efforts to create a characterisation process for waste streams that will be of benefit to those involved in the sentencing, transport and disposal facilities of fissile materials.

5. Conclusions

The characteristics of the fissile nuclear fuel cycle materials transported by the various countries have much in common and so have the designs of the packages to contain them. Experience suggests that there is an opportunity to rationalise the criticality safety methodology in some important areas, notably for the transport of new and spent fuel assemblies and fissile wastes. This in turn potentially could reduce the effort, shorten the time and reduce the cost involved in obtaining approvals.

Production of a WNTI Industry Guide could provide a philosophy and source of technical data (assumptions) to assist applicants in the preparation of safety cases for the transport of new and spent fuel assemblies with a view to achieving this worthwhile rationalisation.

However, it is clear that there will be different ways in which the criticality safety requirements could be satisfied and it is the choice of the applicant which to adopt on the basis of cost/benefit considerations.

The cost of implementing a particular strategy for obtaining a licence, including:

- the cost of analysis, design and manufacture of a package;
- the cost and time involved in obtaining approvals;
- maintenance and operational costs;

has to be compared with the corresponding benefits, of which payload is an important factor.

Nevertheless, if a greater degree of rationalisation in assessing criticality safety consistently and efficiently can be achieved, it could have benefits for all stakeholders. The WNTI Task Force is seeking to contribute to this objective.

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