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Licensing of a Type B(M)F Radioactive Material Transportation Package by Finite Element Analysis

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Abstract

The approval of nuclear transport packages requires the demonstration of performance against regulatory tests. This has typically required a significant amount of physical testing, with concomitant time and cost implications. The capability of analysis techniques used in the nuclear industry for the substantiation of package designs has advanced significantly in recent years, to the point where it has become feasible that little or no physical testing could be required in the assessment of a transport package against the regulatory tests.

A paper presented by Rolls-Royce plc at PATRAM2007 described the use of Finite Element Analysis (FEA) code in the licensing of a new package for the transport of new nuclear fuel. The paper concluded that explicit analysis codes were so reliable for package impact calculations that minimal test work, limited to key confirmatory impact scenarios, should be pursued.

This paper describes the approach taken to successfully gain design approval for a Type B(M)F package without the need for any physical testing, other than simple characterisation studies. It discusses the regulatory background that gave confidence to pursue this analysis-only approach. It then shows the steps taken within the applicant's organisation, and the engagement with the competent authority, to demonstrate compliance entirely in the FEA environment.

Introduction

The use of FEA, as applicable to the substantiation of Radioactive Materials (RAM) transport package designs with respect to impact integrity, has progressed over the years. It has developed from a point where it simply supported the design activity, but played no part in the substantiation, to the point where substantiation takes place via FEA and is validated by the physical testing of a scaled version of the package. The requirement to perform physical scale testing was driven by the need to demonstrate confidence in the modelling and the Quality Assurance (QA) behind the work.

More recently, the IAEA RAM transport regulations have been supportive of an analysis-only approach, with additional guidance from competent authorities. This paper describes the approaches taken to gain a Type B(M)-F design approval with no physical testing, how this was possible within the existing regulatory framework, and how substantiation can be completed entirely via FEA.

Regulatory Framework/Background/IAEA Requirements

The basis of the four possible approaches for design approval of RAM transport packages is described in the regulations:

a) Comparison to similar packages: demonstration by discussion and reference to drawings and/or sketches that the package is, in all respects, better than or equal to, a previously approved package.

b) Prototype testing: direct testing with reliance on the results of the test to demonstrate compliance.

c) Model testing: testing that validates an FEA, in turn demonstrating compliance.

d) Analysis: compliance demonstrated entirely in FE environment with limited physical testing.

For a new package that is dissimilar to any existing design, approaches b) and c) are those normally followed to demonstrate compliance with the regulations. However, these approaches require prototypic packages to be manufactured in support of physical testing. These are usually costly and time consuming, especially in a scenario where the total number of packages to be manufactured is low.

Following the successful approval of a Type 2 Fissile Industrial Package (IP2-F) using the model testing approach, confidence that an analysis-only approach, as described in approach d), could be used was sufficient that it was advocated by Rolls-Royce plc at PATRAM in 2007 (Reference 1).

For a competent authority to approve a package that is substantiated for impact integrity using FEA as its only means of substantiation, confidence in the design and the company QA systems must be demonstrated. This is necessary to ensure that the design not only meets the IAEA regulations (Reference 2), but also demonstrates that the design is robust against the regulatory requirements. This must also be supported by robust and in-depth validation and verification. Each of the UK competent authorities, the Office for Nuclear Regulation (ONR) and Defence Nuclear Safety Regulator (DNSR), and the European Association of Competent Authorities (EACA), provides some guidance on the analysis-only approach; though the guidance statements are not identical.

The competent authority with responsibility for assessing the Type B(M)-F design application against the regulations was the DNSR. The DNSR has produced an Applicant's Guide (Reference 3) that gives clear guidance on the expectations of any analysis-only approach to impact evaluation. Part of the guidance from the DNSR includes how a strategy and justification for an analysis-only approach can be developed by the applicant and agreed with the DNSR prior to submission of the application. It is by this means that the DNSR Applicant's Guide helps facilitate an analysis-only approach.

The European PDSR Guide (Reference 4) does not explicitly discuss the means by which the structural or containment analyses shall demonstrate compliance of the design with the regulations. In Annexe 4 to the guide it does, however, cover the expectations with respect to either an experimental drop testing approach or a calculation approach.

Similarly, the ONR discusses physical testing and mathematical modelling in its guidance for applications (Reference 5). The ONR Applicant's guide also helps facilitate an analysis-only

approach describing how substantiation of the design is allowed in the regulations by physical testing, calculation or reasoned argument.

TCSC 1087

An outline for the FEA process and planning is set out in Sections 2 and 3 of industry standard TCSC1087 (Reference 6). It discusses the steps in the process of completing the FEA for impact assessment of a package. It also lists the QA factors required in delivering any analysis in a robust manner. Finally, it states that advice should be sought from the competent authority at the earliest opportunity.

Compliance Plan

An important part of managing the process of completing an analysis-only approach has been engagement with the competent authority. One aspect of that engagement was the preparation and submission of a compliance plan, which sets out the means by which compliance of the package design with the requirements of the regulations shall be demonstrated.

The compliance plan was prepared as early as possible and concurrent to the design process. It was at this stage that an analysis-only approach was outlined, as permitted by the competent authority in its guidance and suggested in TCSC1087. The competent authority then had the opportunity to comment on the approach detailed in the plan. The comments allowed the competent authority to offer guidance without endorsing the approach. This gave confidence to the applicant that the approach could be pursued, with the emphasis on the applicant being responsible for the approach. Support for the approach was possible because the detail of the compliance plan clearly set out how the regulatory requirements would be satisfied.

Application Submission

The guidance (Reference 3) provided by the competent authority was followed as far as was practicable. The application for design approval of the flask was prepared in much the same way as for similar packages; the analysis-only approach had little effect on the preparation of the Transport Safety Report (TSR).

Compliance with the regulations is demonstrated in the TSR, with the impact evaluation justification presented as simple statements against the guidance. The justification then referenced-out to the significant amount of work done in the substantiation of the design, as discussed in PATRAM2019 paper #1133 (Reference 7).

Regulatory Approval

Once the TSR was complete and submitted, the competent authority completed its review of the substantiation and provided a comprehensive list of questions and observations. These were managed in the manner guided by the competent authority guidance (Reference 3). The questions relating to the impact integrity assessment included several on the analysis-only approach: material properties and material testing; sensitivity studies; bolt modelling; justification for the selection of drop angles; load cases and sub-modelling.

Conclusion

This paper discusses the approach used by Rolls-Royce plc in the successful application for the approval of a transport package where the impact assessments were conducted using FEA as the primary means of demonstration of compliance. This was the first time that this approach was used and has demonstrably removed time and cost from the programme for the delivery of a key customer capability.

In summary, the approach was successful through:

a) Understanding the opportunities given by the regulations and competent authority guidance with respect to an analysis-only approach.

b) Engaging with the competent authority as early as possible in outlining the intention to pursue an analysis-only approach.

c) Having the technical ability to deliver against a compliance plan.

d) Maintaining a robust QA system that supports a consistent approach to FEA.

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