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CONSEQUENCES OF DROP TEST PARAMETER LIMITATIONS FOR SUBSEQUENT PACKAGE DESIGN SAFETY ANALYSIS

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ABSTRACT

A drop test result represents only one "point" in the field of parameters, which a package design approval has to consider. One test parameter e. g. is ambient temperature condition. Using -40°C addresses the most severe embrittlement or stiffness of some cask components. Using maximum operational temperature, plastic deformations are of interest, particularly in the sealing areas to keep leak tightness. The real material properties of the drop test package model are an additional parameter with respect to the range of specified material properties due to quality assurance controls, which are the basis of the subsequent package design safety analysis. The relevance of scaling effects, influence of manufacturing processes, simulation of basket and radioactive content, questions of similarity, limited number of drop tests and drop test positions, temperature effects on impact limiter properties and some other aspects are presented in this paper.

The given drop test parameter limitations require additional safety demonstrations for the package design besides the interpretation of drop test results. The definition of drop test parameters has a significant influence on subsequent package design safety analysis. It influences the safety analyses structure and dictates to what extent these analyses have to be presented in the safety analysis report. The presentation focuses on the consequences of limited results of drop tests due to the above mentioned limitations for subsequent package design safety analysis. This will be underlined by experiences during package design approvals including drop tests.

Missing considerations concerning the selection of drop test parameters can provide severe consequences for subsequent package design safety analysis. Severe consequences, which could not only be provided due to the drop test program itself, but also due to an irrational extent of subsequent safety demonstrations up to the impossibility to demonstrate the compliance with the regulations at all. This leads usually to subsequent design changes, which costs a lot of time and money and rips into the heart of the project. This paper presents possible approaches for the check of parameters before starting drop test programs to avoid those severe consequences.

INTRODUCTION

Package design safety analysis are usually based on a drop test program. Performing a drop test program means a significant effort for the staff. A lot of time and money will be invested. Therefore, a drop test program should be designed in a way to provide the maximum benefit for subsequent package design safety analysis. Safety demonstrations additional to the drop tests should be reduced as many as possible. Nevertheless the experiences usually show unkind surprises facing the final safety analysis report, because the expectations concerning the scope of demonstrations only based on the already performed drop tests are not fulfilled.

The unkind surprises are often caused by limitations of the drop tests due to testing conditions as ambient temperatures or manufacturing influences as material properties. The drop test is only one point in a field of parameters. The art is the positioning of this point in the parameter field to reduce the effort for subsequent package design safety analysis.

The accompanied problem is the large variety of parameters. To give some advice tackling this parameter jungle is the objective of this article. At first, the parameters are splitted into three groups: safety requirements related to TS-R-1 §6xx, testing conditions mainly provided by §7xx and influences of manufactured design, which touch also quality assurance needs [1]. Finally, there will be an approach for a rather complete view to drop test parameters with respect to the remaining subsequent package design safety analysis.

SAFETY REQUIREMENTS

First dimension of the mentioned parameter field are the safety requirements usually found in the §6xx of TS-R-1 [1]. Based on the main safety objectives as leak tightness, integrity of the enclosure, sufficient shielding of the radioactive materials in the package and subcriticality, subsequent safety requirements add as temperature limits, corrosion protection, limits for thermal elongation, e. g .

Any drop test will usually address some of them, but not all. If we want to address subcriticality input parameters as integrity of the cladding or neutron absorber repositioning, the content should be experimentally modelled to meet either brittle fracture safety or maximum deformations. Both objectives, maximum deformations and brittle fracture safety can not be met in parallel. A similar problem, we are faced by enclosure demonstrations: To meet leak tightness, plastic deformations in the flange area of the shell should be avoided, but the integrity will be demonstrated by brittle fracture toughness. For brittle fracture demonstrations, the structure are optimised for maximum hardness. To enable maximum deformations, the weakness of the structure is the decisive factor.

To meet shielding requirements, the stability of some materials in the cask is usually necessary. Most of this materials are not only affected by mechanical stresses, but also by thermal ones. Therefore, a test of thermal load for routine conditions or even the fire test will be rather penalising than a drop test.

TESTING CONDITIONS

Another parameter dimension is given by the testing conditions, usually provided by §7xx of TS-R-1 [1]. In addition to single drop test scenarios for normal and accident conditions, the required most damaging combination of drop tests opens a widely spread variety for possible drop test sequences. A combination of a 0,3 m drop required by normal conditions with a 9 m horizontal drop can be also put in practice as a puncture drop followed by a 9 m vertical drop and vice versa. We can have two or even three single drop tests in one line to provide the most damaging appearance for the subsequent fire test.

The drop test model can be manufactured in different ways. At first, we often take credit of the scaling laws and test a 1:2 or even a 1:3 scaled specimen [2] [3]. Next influence will be the widely used simplification of the content modelling as far as the safety objectives tolerate, which you want to demonstrate. Some design changes in comparison to the original package will usually take place in a drop test model and can limit your demonstration purposes.

The ambient conditions of a drop test give another point in the parameter field. Ambient temperature and solar insolation should be mentioned here at least. Ambient conditions are usually difficult to realise for a drop test, because they can hardly be influenced.

The test specimen properties represent another parameter. The material properties for the most important design parts of the test specimen are usually measured and represent a single point within a range of possible properties defined by quality assurance inspections.

MANUFACTURED DESIGN

The third dimension of parameters are the ones connected to the influences of manufactured design. In addition to geometrical tolerances, there are acceptance criteria for material properties, the application of manufacturing processes as welding, forging or casting which influences significantly the resulting packaging properties. This parameter dimension usually gives minimum and maximum characteristics for the package design.

The scaling of a drop test model, for instance, is limited by the standardisation of design parts as bolts and seals. Therefore, it is not possible to realise a scaling for the sealing area completely with the same proportion [4]. The tightening torque for the drop test specimen can be measured, but it will not cover the whole range of the dimensioning tightening torques, which could be between minimum and maximum.

A welding design for the packaging can be performed in different ways and the welding process applied for the test specimen can be different to the one for the original package.

For the drop test specimen, we will usually get measured material properties for the most important design parts. But for safety analyses we have to consider the whole range of material properties, which are determined by the specifications for quality assurance.

Geometrical tolerances are of interest for thermal tests, because the dimension of existing gaps influences the resistance to heat dissipation significantly. But also for mechanical tests, the gap between lid and shell flange influences the possible ovalisation considering a horizontal drop.

Another influence is given by the ambient testing conditions. There are ambient temperature as well as package temperature due to operational conditions and in particular for thermal tests solar insolation and air flow for heat dissipation by convection has to be considered. Some shock absorber materials as wood for instance are significantly influenced by temperature conditions [5]. This leads to a stronger or weaker drop test performance, which can cause higher stresses due to a hard shock absorber material as well as a forced

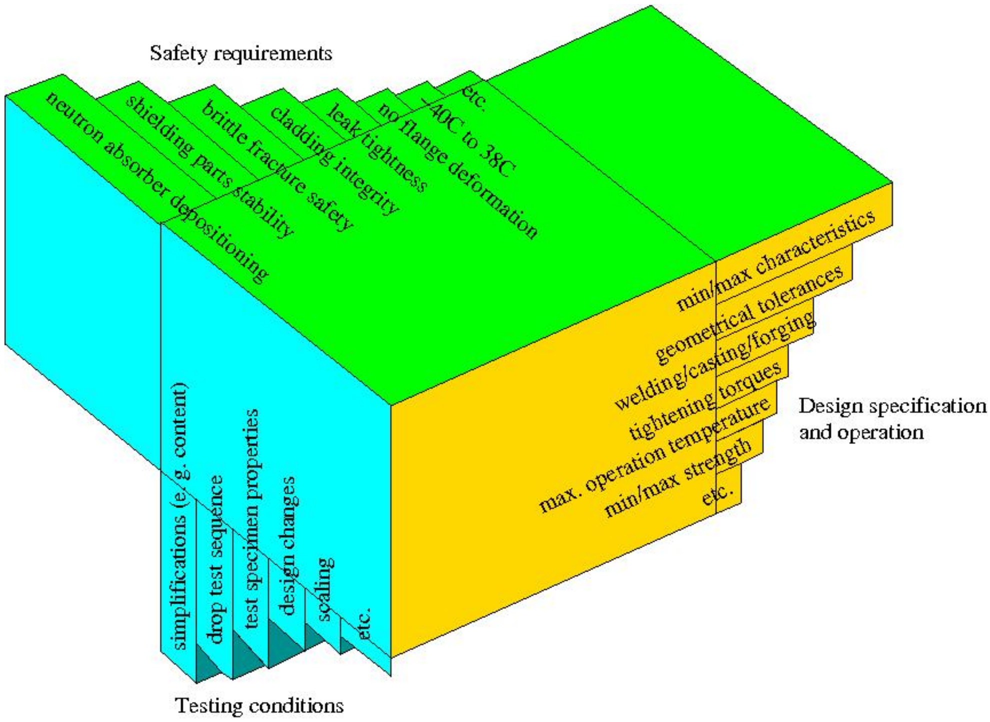

Figure 1: The Assessment Cube: three dimensional array of parameters for drop test limitations

penetration of the body due to weak shock absorber properties.

ARRAY FOR SAFETY ANALYSIS: THE ASSESSMENT CUBE

The three dimensions of parameters discussed above can be understand as an three dimensional array. Tracing to the safety cube of Schneider for civil engineering [6], which is based on the morphological box of Zwicky [7], this three dimensional array is called here the *Assessment Cube*.

Figure 1 demonstrates the basic approach: The green coloured parameter set represents the safety requirements as neutron absorber repositioning, shielding parts stability, brittle fracture safety, cladding integrity, no flange deformation or leak tightness at all. The blue coloured side of the cube opens the testing conditions dimension: modelling simplifications as for the content, the selected drop test sequences, design changes, scaling or test specimen properties at all. The yellow coloured influences of manufactured design include geometrical tolerances, manufacturing processes as welding, casting, forging, used tightening torques and the range for minimum and maximum characteristics at all due to design specification and operation.

Some parameters itself opens a range as minimum and maximum values for material properties and tightening torques or the requirements for ambient temperatures defined by the regulations [1]. Others give rather qualitative values as the safety requirements, which are addressed or not by the drop test. Nevertheless, the extent of fulfilment of those safety requirements can also give a parameter range.

USE THE CUBE

The provided *Assessment Cube* gives an overview for possible parameters, a classification for them according to TS-R-1 and helps to classify a drop test scenario within the parameter set. This section gives some examples for the latter.

Facing a 9 m drop test in horizontal position at room temperature at first, we discuss the testing conditions with respect to the safety requirements brittle fracture safety and leak tightness. Brittle fracture safety is not addressed directly due to the missing flaw. But we can determine the highest stresses to enable a subsequent analysis by calculation. The highest stresses will be find either using the highest strengths for shock absorbers or for the lowest strengths to enable cask penetration. The first solution requires minimum temperatures as -40°C and the latter maximum operational temperature [5]. That means, we have to move the drop test condition temperature to one of these extrema to get the highest stresses. A corresponding material substitution for the shock absorbers can be a solution, too. The optimal solution can be found by pre-calculations, which give at least a qualitative view on the several possibilities [8].

In addition to scaling problems [4], flange deformations are a criteria for leak tightness. These deformations will be favoured by weak drop test conditions, that means high temperatures and low yield strength for the shell. Therefore, operational temperatures should be addressed. Lowest temperature range as -40°C is not helpful for this kind of demonstration. In addition, geometrical tolerances as for the gap between lid and shell flange will also be important for the possible relative movement of the sealing surfaces during horizontal drop. This movement can influence the seal surface and therefore the leak rate in particular for metallic seals. Even the ovalisation effect is influenced by this gap and therefore the stresses in the flange area. Accompanied tests for special design parts as seals [9] or shock absorbers can help to close the demonstration gap between drop test conditions and the range within safety requirements have to be fulfilled.

Looking at a vertical drop with respect to subcriticality, the behaviour of the fuel element array is of interest: On the one hand we want to get information about cladding integrity and on the other hand we are interested in fuel element array deformations and the position with respect to neutron absorbers. Again, cladding integrity is addressed by hard conditions and maximum deformations require weak conditions or material properties. In addition, an assessment requires the sufficient modelling of the internal arrangement: simplifications as material substitutions should be selected with respect to subcriticality demonstrations.

If we are rather interested in leak tightness during vertical drop, the internal arrangement should be modelled in a way to get information or better a conservative behaviour of additional impacts of the internal arrangement onto the lid.

There are a lot of other examples possible, which are not mentioned here, to position a drop test due to its testing conditions within the parameter field of manufactured design and determine the extent of fulfilment of safety requirements. This extent gives an idea of the additional effort for subsequent package design safety demonstrations. Experiences in the past show, that pre-calculations are helpful to find an optimised position of the drop test within the parameter field considering drop test limitations, and thus, to reduce the additional effort for subsequent safety demonstrations.

CONCLUSIONS

Safety analysis for RAM packages has to met the safety requirements of TS-R-1 [1]. Most of them are provided by section VI. Some of them are discussed here with respect to the main safety objectives as leak tightness, integrity, shielding and subcriticality.

Section VII of TS-R-1 provides the testing conditions under them the safety requirements has to be fulfilled. There is a deep relationship to the way drop tests are performed. The combination for the most damaging scenario, modelling simplifications for the content for instance, ambient conditions or just scaling are some of the main influences on this topic.

In addition, packaging properties owing to the influences of manufactured design are discussed as the third dimension of parameters. Manufacturing tolerances, manufacturing processes and material properties are examples for those parameters. There is a special connection to quality assurance requirements.

Safety requirements, testing conditions and manufacturing influences give three dimensions of parameters. The properties of a drop test specimen in addition to the performed drop test represent one point in this array of parameters, which is called here the *Assessment Cube*.

Understanding the cube idea will enable the user to recognise the limitations of a drop test and a drop test program respectively. It should be possible to get the extent of the package design safety analysis subsequent to a drop test program.

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