Session H
Package Challenges:
Large Components and Long-term Aging and Storage

Assessment of Ductile Cast Iron Fracture Mechanics Analysis
within Licensing of German Transport Packages


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Overview

1. Introduction
2. Mechanical Design Requirements
3. Finite-Element-Model Verification
   *(1m Puncture Drop Test)*
4. Fracture Mechanics Assessment
5. Conclusions
Introduction

Type B(U) package - accident conditions of transport (mechanical tests)

1m puncture drop test  Sequence  9m drop test

Demonstrations of compliance

Tests with specimen and/or samples  Reference to previous demonstrations  Test with scale models  Calculations by using conservative parameters

In practice a combination of these methods is usually applied
Para 657  Type B(U) packages shall be designed that if it subjected to:

(a) …  

(b) The test specified in paras 726, 727(b), 728 and 729 and the tests in paras:

(i) 727(c) … Drop III - crush test

(ii) 727(a) … Drop II - 9m drop test

• Retain sufficient shielding …

• Restrict the accumulated loss of radioactive contents …
1m Puncture Drop Test

Experimental investigations

1m puncture drop test with half-scale model of a HLW cask

Deformed puncture bar after drop test

(GNS CASTOR HAW/TB2)
1m Puncture Drop Test

Deformed puncture bar (half-scale model)

Finite Element Analysis

Drop Test

radial deformations
Investigation of mesh refinement

1m Puncture Drop Test

Initial Mesh

1st refinement

2nd refinement

Max. Principal Stress [MPa]

Time [µs]

Measured Strain
Calc. Strain (Truss)
Calc. Strain (IP)

Strain [-]

Time [µs]
1m Puncture Drop Test

FE half-scale model

FE full-scale model

FE full-scale model is used for application in the safety assessment of the original package design
Fracture Mechanics Assessment

Guideline for Assessment of Ductile Iron Cask Components

- Concept bases on principle of preclusion of crack initiation (IAEA TS-G-1.1, App. V)
- Postulated material defects are modelled as sharp cracks
- Methods of linear elastic or elastic plastic fracture mechanics have to be used in dependence of the material behaviour

Criteria:
Failure by fracture can be avoided if:

\[ K_{\text{appl}} < K_{\text{mat}} \quad \text{or} \quad J_{\text{appl}} < J_{\text{mat}} \]
Analysis steps of fracture mechanics assessment of transport containers made of DCI

1. Global finite element analysis of the container

2. Specification of critical positions

3. Specification of the dimensions of the potential flaws

4. Reduction of the number of potential crack positions

5. Specification of finite element sub-models containing cracks

6. Determination of dynamic crack driving force

7. Safety assessment
1. Global finite element analysis of the container

Finite-element-model of the container (without flaw)

Dynamic numerical analysis

Intersection A

Stress distribution
2. Specification of critical positions

According to German Guideline BAM-GGR 007:

Positions where the maximum principal stress is greater than 50 % of yield stress of the material

Stress distribution of global numerical model
3. Specification of the dimensions of potential flaws

Defect assumed as embedded crack with its plane normal to the largest principal stress

Re-characterisation of the circular crack as a semi-elliptical one of identical area as the equivalent reflector size (ERS)

\[ a^* = \frac{k}{\sqrt{12}} \text{(ERS)} \]

Shifting the crack towards the surface until the criterion for re-characterising it as surface crack

\[ h \leq 0.4 \cdot a^* \]

Determination of the dimensions of the semi-elliptical surface crack

\[ a = 2a^* + h \quad 2c = 6 \cdot a \]
4. Reduction of the number of potential crack positions

Potential crack positions
5. Specification of finite element sub-models containing cracks

Global model without cracks

Sub-model with cracks and boundary conditions

Plane of symmetry
6. Determination of dynamic crack driving force

Sub-model with boundary conditions of the global dynamic model
7. Safety assessment

Fracture Mechanics Assessment

Crack model

J-Integral

\[ K_{\text{appl}} < K_{\text{mat}} \quad \text{or} \quad J_{\text{appl}} < J_{\text{mat}} \]
Conclusions

1. Fracture mechanics assessment in compliance with IAEA-regulations

2. Use of handbook solutions impossible

3. Finite-element analyses performed in two steps:
   - stresses and strains on global model without flaws in conjunction with experimental results
   - Sub-modelling of critical positions with assumed cracks

4. Requirements in non-destructive inspection