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QUALITY ASSURANCE REQUIREMENTS FOR MECHANICAL TEST CAMPAIGNS OF PACKAGINGS

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ABSTRACT

A management system based on international, national or other standards acceptable to the competent authority shall be established and implemented for all activities including design, manufacture, testing, documentation, use, maintenance, inspection in accordance with IAEA SSR-6. Hereby, quality assured testing and documentation can substantially contribute to the demonstration of package design compliance with the regulations. Nowadays, a drop test campaign within the approval process of packages for radioactive materials can be a very complex and extensive project including various test and measurement techniques. On this basis of procedures and documents the experimental tests of packages and containers are performed with quality proofed results and a high reliability. A complete traceability and direct transferability of package design test results can give particular importance to the type approval procedure.

INTRODUCTION

Mechanical testing in the sense of the IAEA regulations [1] means: Assessment of package safety performance under all relevant regulatory requirements, using experimental testing of small- or full-scale package specimens, reference to previous satisfactory tests of sufficiently similar nature, and conservative calculations, or a combination of all methods.

In recent years full-scale and small-scale model testing according to most damaging drop sequences and attitudes, with variations of test temperatures, package properties and design changes, have been performed by organizations responsible for mechanical testing like the Federal Institute for Materials Research and Testing (BAM) and have taken a wide range of individual test and measurement methods as well as further developments in experimental testing and numerical calculation. It was also shown by various safety analysis reports that a complete safety case usually has to be assembled by a complex combination of nearly all test methods:

- Structural analysis may require pre- and post-test calculations, and additional coverage e.g. by material or component testing.
- Small-scale model testing needs more complicated measures for correct transfer of test results to the original design to be approved.
- Numerical calculations need verification based on experimental tests.

Within approval and licensing of packages for the safe transport and storage of radioactive material the performance of drop tests is based on comprehensive and systematic procedures

with very detailed documentation of both, determination and evaluation as well as parameter and data of mechanical testing. Examples of comprehensive mechanical test campaigns performed recently by BAM are given in [2] for a storage container and in [3] for a half-scale test model of a transport cask.

QUALITY ASSURANCE SYSTEM

In order to guarantee sustainable assurance of mechanical test results delivered to the approving authority as well as to applicants or customers, BAM shall, at its own responsibility and for the duration of the drop test performance, establish, operate and maintain an effective quality management system designed to ensure that the applied test methods meet international accepted quality requirements.

The section of BAM responsible for experimental testing of containers has been working since 2004 as a testing laboratory holding the accreditation acc. to ISO/IEC 17025 [4] by the DAP (German Accreditation System) in mechanical testing within design approval procedures of RAM packages, especially related to drop test performance and leakage testing.

BAM's own quality assurance management system is independent as well as process governed [5]. This complete quality assurance plan encompasses both, quality assurance (QA) and quality control (QC) functions. QA involves meeting programmatic requirements but on occasion requires the implementation of external checks on testing quality. These external checks include independent system audits, third party sample and analysis for accuracy and precision or comparison to calibration standards. QA audits also confirmed operational and maintenance procedures are being properly implemented. Conversely, Quality Control functions in the sense of the responsible mechanical testing laboratory are usually a series of frequent (daily, weekly, monthly) routine internal checks, such as system inspections, periodic calibrations, and routine maintenance.

Measurement methods in context of QA

The quality management manual represents the guidelines which describe procedures and standard working methods for quality assurance.

In drop tests for demonstrating ability of a package to withstand normal and accident conditions of transport the sensor instrumentation of a specimen is a very important tool to evaluate the mechanical behavior during its collision with the unyielding target. Generally, the instrumentation incorporates the measurement of strains, accelerations and temperature at the package. Test results as deceleration-time functions and strain-time curves constitute a main basis for the validation of assumptions in the safety analysis, for the evaluation of calculations based on finite-element methods and extrapolation of scale model testing on full sized package within approval design tests.

Indispensable are measurements concerning leak-tightness of the closure lid system. Additionally, specific photogrammetric measurements have been used to characterize the conditions of the closure lid system after drop test in more detail. In case of remarkably increased leakage rates, heavy strained lid bolts or significant tensile or compressive stresses of the lid, the flatness of sealing area and circularity of the cask lid flange could be investigated more closely, e.g. by using surface roughness tester as well as 3-d coordinate measurements in order to evaluate the mechanical impact behavior of the casks flange region after the drop test sequence.

The collecting of data which are obtained by means of different test and measurement methods are followed by the preparation and interpretation of mechanical test results, and include also possible correlations between such characteristics like mean rigid body deceleration, local stress-strain behavior, and amount of plastic deformation caused from the force of impact or collision.

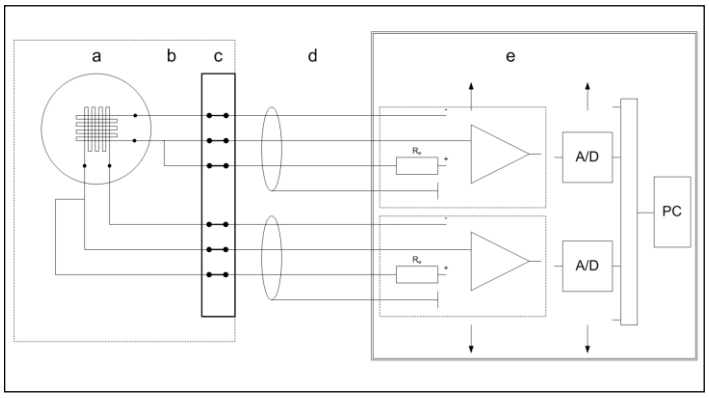
Estimation of measurement uncertainty

Because of all measurements are subject to uncertainty a measured value is only fully complete if it is accompanied by a statement of the associated uncertainty. In most cases the estimation of uncertainty characterize the dispersion of the values attributed to a measure quantity. Hereby, the relative uncertainty is the single measurement uncertainty divided by the measured value. But, for the strain measurement chain (see Fig. 1) or complex measurement system like the leakage rate testing of the specimen the overall measurement uncertainty has to be analyzed more sophisticated by means of combined standard or expanded uncertainties.

The taking into account the measurement uncertainty can be done according to GUM, the guide for the expression of uncertainty in measurement [6], which has been adopted by all major national measurement institutes and by laboratory accreditation standards such as ISO/IEC 17025 which is the guiding principle for BAM's accreditation.

Generally, in a test report of BAM the measurement uncertainty is given when it is of

- importance for the validity and acceptance of the test result,
- or measuring for the compliance of value limits,
- and at any time on customer specific request.



a) X-Y foil strain gauge, ***b)*** Ribbon cable (coded) passed along the cask, ***c)*** Soldering terminal, ***d)*** Cables, ***e)*** Portable data acquisition device containing bridge amplifier, transient unit and computer [7]

Piezo-resistive accelerometers in 6-wire Wheatstone full bridge circuit

XY/XYZ Strain gages in 3-wire Wheatstone quarter bridge circuit

50 m long shielded cables; soldering terminal

Multi-channel measuring devices with analogue bandwidth up to 200kHz, 3dB and differential bridge amplifiers

100kHz pre-sampling filter; 500MHz sampling frequency per channel; 12-bit and 16-bit vertical resolution

Fig.1: Schematic view of strain measurement chain (left), and parts of measuring system (right) under consideration for the estimation of expanded uncertainty of electronic data.

PRECONDITIONS FOR MECHNICAL TESTS WITH RAM PACKAGES

For the conduction of mechanical test campaigns with RAM packages the following assumptions must be given:

- Complete development of the conceptual design and layout up to the detail mechanical design and dimensioning.
- Approved drop test specification with mechanical drop test positions and sequences in order to meet the most-damaging-criteria for all safety-relevant package components, also with consideration of the subsequent thermal test and based on adequate reasoning of modeling and its validation.
- Design and manufacturing of the test specimen under consideration of preliminary technical examination, quality-assuring controls and acceptance by independent experts.

PACKAGE TEST SPECIMEN

In Germany, external experts have to check on behalf of the approval authority the technical documentation of the test specimen presented by the manufacturer for plausibility and completeness as well as in accordance with the requirements as given in para. 713 of the regulations [1]. The detailed documentation of the test specimen in terms of the receipt documentation is generally followed by the certificate of conformity as well as the confirmation of testability of the specimen. In comparison to the final design the drop test specimen has to take the verification of designed parameters, e. g. inventory, weight, shielding, and loading assumptions into account so that differences can be satisfactorily assessed.
On arrival of the test specimen at the test facility the geometrical positions and main dimensions of selected components, test models sections and samples are checked and registered in the test documentation. Therefore, such documents as parts and materials lists, listing of deviations and corresponding single non-conformance reports, technical drawings like as built drawing and documentation are needed.

TEST PROGRAM

The approved test program includes the specification of investigations and methods as given in Tab. 1 for the main topics within mechanical test campaigns of packages.

Tab.1: Specification of investigation and methods within a drop test program.

Specification of Drop Test Program	
Specific topic	**Basic Measuring Methods**
Stress analysis	Accelerometers Strain gages Pressure indicated film
Deformation analysis	Recording: High-speed video, video, photo Manual surface shape measurement Tactile roughness and contour measurement 3-d measurement by optical fringe projection and close range photogrammetry
Integrity analysis	Visual inspection NDT methods: Leakage testing Surface crack testing Tightening torque of bolts and screws

In general, the test program comprises a wide range of instructions for testing:

- Drop test sequences with regard to the safety-related acceptance criteria (see Fig. 2) as well as a corresponding measuring program;
- Test procedure plans with test steps for preparation and performance of mechanical testing in order of processing as well as with determination of execution;
- Work and testing instructions for single testing and measuring methods, especially those with focus on stress, deformation and integrity analysis;

- Instrumentation plan for sensor positioning and application in accordance with each single test;
- Description of general test equipment and essential methods;
- Handling concept for safe lifting and positioning of the test model regarding to drop orientations as well as the utilization of different test procedures;
- Responsibilities of involved parties
- Time schedule and project monitoring adjusted to general test planning.

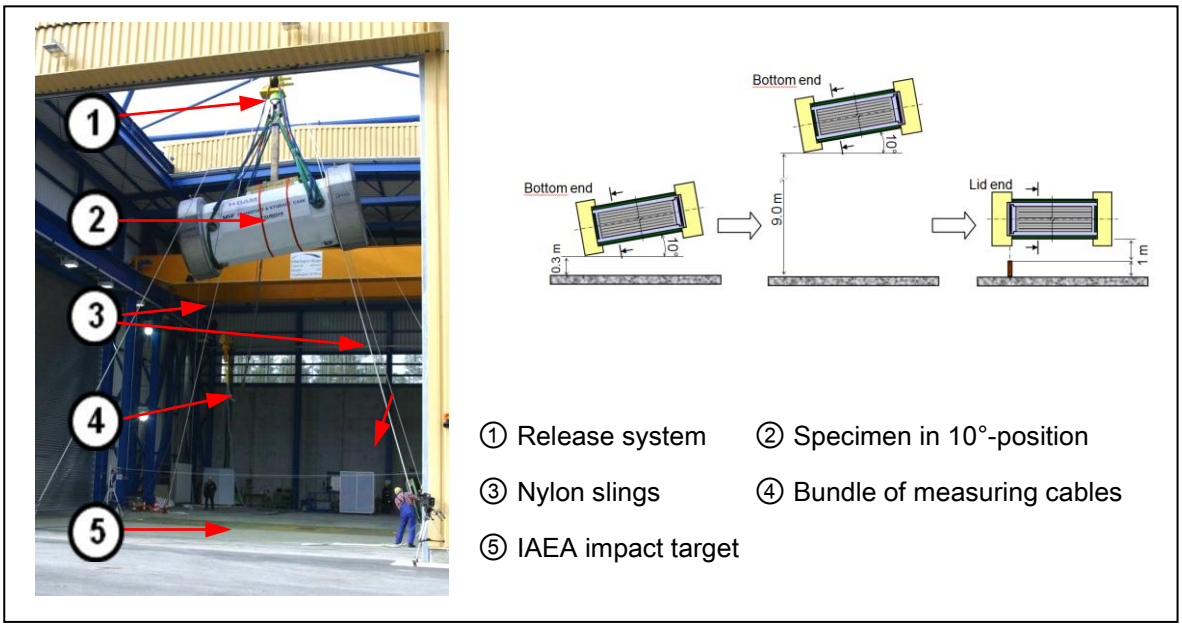


Fig. 2: Drop test setup and sketch of mechanical test sequence including in a test program for demonstrating compliance for NCT and ACT, respectively

QA DOCUMENTS FOR DROP TEST PREPARATION AND PERFORMANCE

Responsible person for the overall conduction of preparation and test performance is the testing group leader. Together with the quality inspector for the mechanical tests he is in charge for the approval control of test procedure plan, technical documentation, drawings, test specifications and measurements plan. With appropriate planning by both, project manager and QA representative the test campaign can be optimized regarding the certainty of results as well as the schedule for completion of the mechanical tests.

Test Procedure and Performance Plan

Within the performance of drop test the task area and assignment are clearly defined, responsibilities have to be fixed between tester, customer or applicant. Test procedure plans comprise work and test steps to be performed in a chronological order, and with reference to manufacturer documents. The test procedure plan as a whole is equivalent to a complete documentation of test preparation and test performance containing confirmation for each single test step by signatures of responsible QA parties as well as the test leader. The test performance has to take into account the safety concept for the operation of the drop test facility, standard work instructions in detail as well as expertise and technical experiences of testing personnel. All single or intermediate steps used to be documented and recorded in order to enhance traceability of mechanical testing.

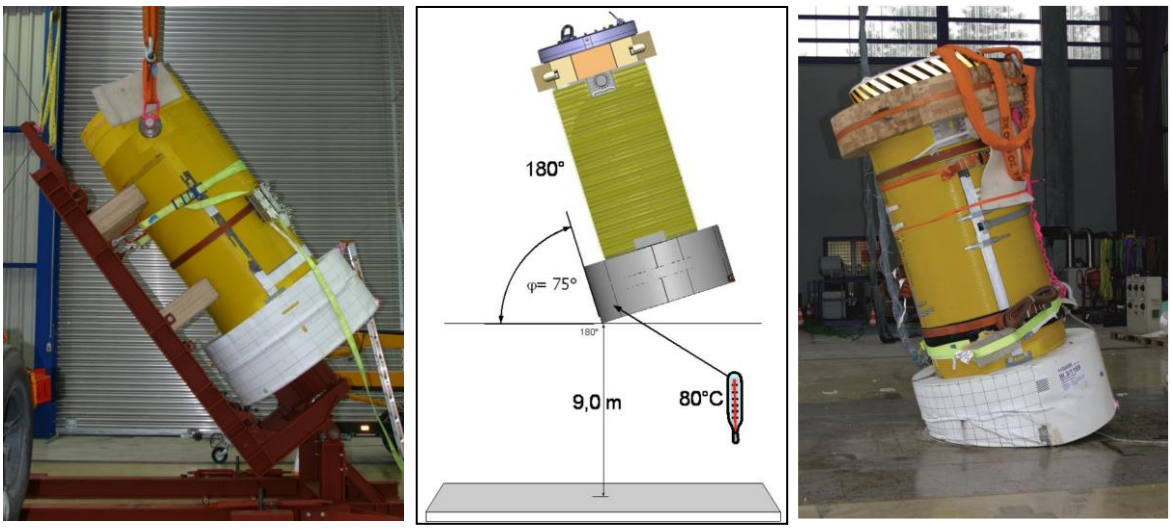
The ***instrumentation plan*** is based on expected stresses and strains according to the proofed pre-calculation for various drop test scenarios and has to take specific aspects of the design, geometry and material of the specimen into account. The intention of this document is to comprise also information in more detail concerning sensor types to be installed on sectional part of the test model or prototype, the coordinates for installation as well the installation work and test steps in more detail. Furthermore, the documents also include the inspection of applied strain gages and mounted accelerometers, measurement of electrical values like ohmic resistance after soldering, check of the whole measurement chains, calibration and zero-setting of the measuring channels.

Testing Methods and Equipment

Appropriate verified test procedures are operated by high-skilled test personnel. The test procedures include mechanical testing equipment as well as electronic testing devices and instruments. Calibrated measuring equipment is properly utilized and kept in readiness. Test equipment and tools are serially numbered and clearly marked with valid calibration certificates.

Standard operating instructions, for example for the determination and calibration of drop height as well as for the test leak guarantee traceable test procedures and measured parameters. The documentation and maintenance of the drop test facility also include the inspection of the planarity of the unyielding impact target as well as labeling of correct identification marks on it. The mechanical characterization of the target's rigidity is based on experimental results from various drop tests [8]. Furthermore, hoisting devices like winch and portal crane as well as the momentum-free release systems are periodical assesses within a maintenance schedule and by means of in-service inspections.

For lifting and positioning of test models and prototypes handling concepts are established including the proof of load-bearing components like lifting yokes or slings and corner jigs. The adjustment of specific drop orientations should taken into consideration the objective of the mechanical test as well as the safety concept within the test performance, see Fig. 3.



(a) Positioning and lifting (b) Drop test parameters (c) Specimen after impact [9]

Fig. 3: Positioning of the specimen in compliance with drop test parameters: drop height 9m, drop angle 75°, specimen temperature 80°C

CONSLUSION

A consistently high quality and reliability of mechanical design tests, as an integral part of design approval procedure for packages for radioactive materials can only be achieved if the quality requirements for manufacture and testing of prototypes and test models are clearly defined, the requirements for the quality management system are specified and the quality control methods, including those adopted under the quality management system, are documented accurately. Based on an excellent quality assurance those investigations and test results can provide objective evidence and high reliability for the tested specimen or prototype within the design package approval in order to demonstrate sufficient compliance with the requirements.

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