Basic tests on 48Y-Cylinder for Integrity Evaluation

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INTRODUCTION

The present IAEA regulations for transport have not yet required fire resistance (800℃,30min) for packagings for natural uranium-hexafluoride. However, fire requirements will be implemented in accordance with the revision of the IAEA regulations in 1996. The integrity of 48Y-cylinder in fire conditions was evaluated using experimental and analytical data. When thermal analysis is performed, various thermal parameters are required. Among these parameters, the outer surface emissivity of the packaging is very important in evaluating heat input from the fire to the cylinder. The IAEA regulations require that the surface emissivity is either 0.8 or the value that the package may be demonstrated to possess if it is exposed to a specified fire. In this study, the emissivity of carbon steel used for 48Y-cylinders was measured to evaluate their fire resistance at the Central Research Institute of Electric Power Industry (CRIEPI). Furthermore, when a 48Y-cylinder is involved in a fire accident, it is engulfed in the fire and the structural strength decreases. There is insufficient data on the structural materials at high temperature because the carbon steel used for 48Y-cylinders is for moderate-/lower-temperature service. Tension tests were carried out to obtain data on tensile strength, etc. at the CRIEPI under the contract from the Science and Technology Agency (STA) of Japan.

TENSION TEST OF CARBON STEEL FOR MODERATE-/LOWER-TEMPERATURE SERVICE

Now SA516 Gr.55, 60, 65 and 70 (ASME Standards) that are the carbon steel for moderate-/lower-temperature service is used for structural material of natural uranium-hexafluoride transport cylinders. Because these materials are not generally used for high temperature service, strength data (0.2 % proof stress, tensile strength, etc.) at temperatures above 500℃ has not been obtained. Therefore we have evaluated the integrity of transport packaging by using extrapolated data obtained at temperatures from below 500℃ for strength data of temperature about 800℃ which becomes a problem for fire resistance test. In this study, we obtained strength data under high temperatures up to 900℃ by tension test, and made evaluation of the integrity of transport packaging more reliable.

We presently chose two kinds of test materials from four kinds of structural materials (Gr.55, 60, 65 and 70) of 48Y-cylinder. One is Gr.60 and the other is Gr.70. Furthermore, test pieces for the tension test were taken from a part of weld joint in addition to a part of the base metal. In the actual conditions of a fire accident, the cylinder's inner pressure increases as uranium hexafluoride vapor pressure rises as its temperature rises. We should evaluate the effect of cylinder's inner pressure increasing speed on structural material because mechanical strength of metallic material is dependent on strain velocity. And then, we confirmed the effect of strain velocity on the strength by performing tension tests in which strain velocity is near the values inferred from pressure increasing speed calculated by fire resistance analysis.

Test Method

The method of tension test at high temperature conformed with ASME code, and tensile velocity was 0.25 mm/min before near 0.2% proof stress and 3.0 mm/min over 0.2% proof stress in ordinary tension tests at high temperature. Furthermore, in the test to evaluate the effect of strain velocity, tensile velocity was 0.005 mm/min, which is the slowest velocity of the test machine (the calculation results by former fire resistance analysis of strain velocity is 0.0015 mm/min).

Fig.1 shows a form of test pieces. Test pieces were taken from both the base metal part and weld joint part of the weld joint block. Both its heat treatment condition and its weld condition were same as those of the 48Y-cylinder. There was difference of weld joint method between cylinder made in the USA and the one made in Europe, so we provided two test specimens, one made in the USA and the other in France, and performed tension tests by using both of the test specimens to compare effects of weld joint conditions on the strength. Table 1 shows a test table.

Test Results

Fig.2 shows test results in addition to transformation point inferred from the carbon content of specimens. Tensile strength and 0.2% proof stress decreased with temperature increasing, but it confirmed that measuring values at temperature above 500℃ were not much different from the former extrapolated values. About elongation and reduction of area, it was confirmed that great change was caused when the temperature exceeded the AC_1 transformation point close to 723℃. About the comparison on tensile strength between base metal pieces and weld joint pieces, as all broken points of weld joint pieces were base metal zone, the measuring values of weld joint pieces were a little greater than those of base metal pieces for the thermal effect of weld. About the tension tests at high temperature where strain velocity was changed, (test pieces were weld joint pieces of SA516 Gr.60 steel made in France), when the strain velocity was slow, tensile strength decreased at temperature 500℃ and 750℃ compared with ordinary tension tests at high temperature. Broken points at every two test pieces were base metal zone at 500℃, base metal zone and heat affected zone at 750℃, and weld metal zone and heat affected zone at 900℃.

MEASUREMENT OF EMISSIVITY

When the evaluation of fire resistance of natural uranium hexafluoride packaging is performed, the outer surface emissivity data of the packaging is required. In this study, the emissivity of carbon steel (SA516 Gr.60) used for structures of 48Y-cylinders was measured under the many conditions of temperature and surface transaction of test pieces (paint, sand-blast, etc.). Emissivity were calculated by using a correction equation. Parameters were measuring values of temperature of test pieces that were measured by using both an infrared radiation thermometer and thermocouples at the same time at high temperature.

Test Method

The test pieces were 15-mm square and 3-mm thick. They were heated by an electric furnace. Fig.3 shows the construction of measuring apparatus. The temperature of the electric furnace was automatically controlled and its upper limit of temperature was 1000℃. The infrared radiation thermometer was fixed above the electric furnace, and measured the temperature of test pieces through an adiabatic glass (sapphire) window and a reflecting mirror. The thermocouples were inserted into a hole 2-mm in depth and 2-mm in diameter drilled on the reverse side of test pieces, and measured those temperatures. The test pieces that the thermocouples were fixed on were set on the table in the electric furnace to be heated step by step, and measured the emissivity at every step. The heated temperature step was from 50℃ to 100℃. Table 2 shows the variation of test pieces.

Test Results

Fig.4 shows the results of measuring emissivity. Measuring values of emissivity at low temperature below 300℃ varied according to the conditions of surface transaction, but at high temperature above 400℃, it took a uniform value '0.6' independent on the kind of surface transaction. It is considered that the paints burned and came off and oxidized on the surface of test pieces at high temperature.

CONCLUSION

In this study, it was carried out that tension test of carbon steel for moderate-/lower-temperature service that is used for structural material of 48Y-cylinder at high temperature, and material strength data was obtained. By the test results, it confirmed that measured strength data at temperature above 500℃ did not make much difference from the former extrapolated data. And, the surface emissivity of a cylinder which is important to fire resistance analysis was measured at temperature below 800℃, and it confirmed that the emissivity is about 0.6 at temperature above 400℃.

Table 1 Test table of Tension tests

Test piece		Test condition	
Specifications	Type	Temperature	Tensile velocity
SA516 Gr.60	Base Metal	R.T～900℃	Before 0.2% proof stress : 0.25 mm/min Over 0.2% proof stress : 3.00 mm/min
	Weld Joint	R.T～800℃	
SA516 Gr.70	Base Metal	R.T～900℃	
	Weld Joint	R.T～800℃	
SA516 Gr.60	Weld Joint	500℃×2 t.p 750℃×2 t.p 900℃×2 t.p	0.005mm/min

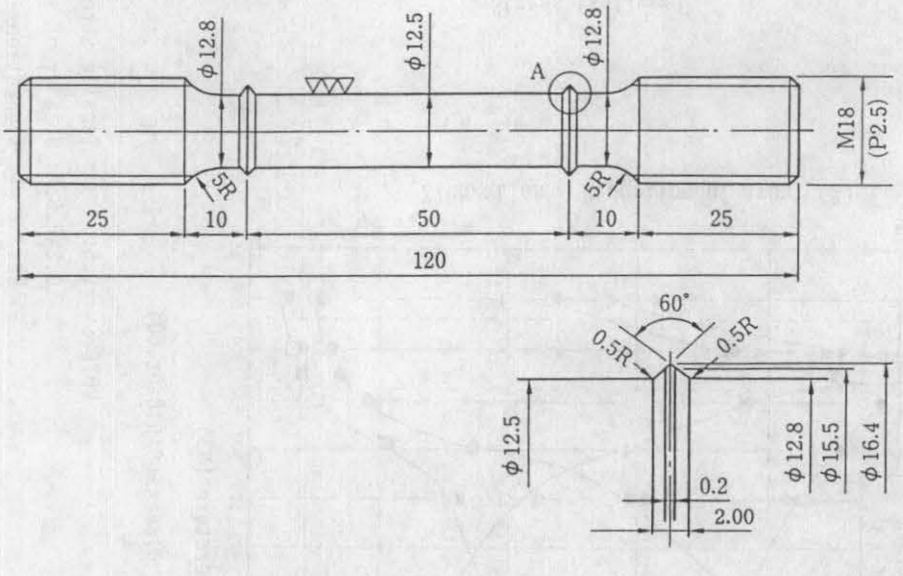
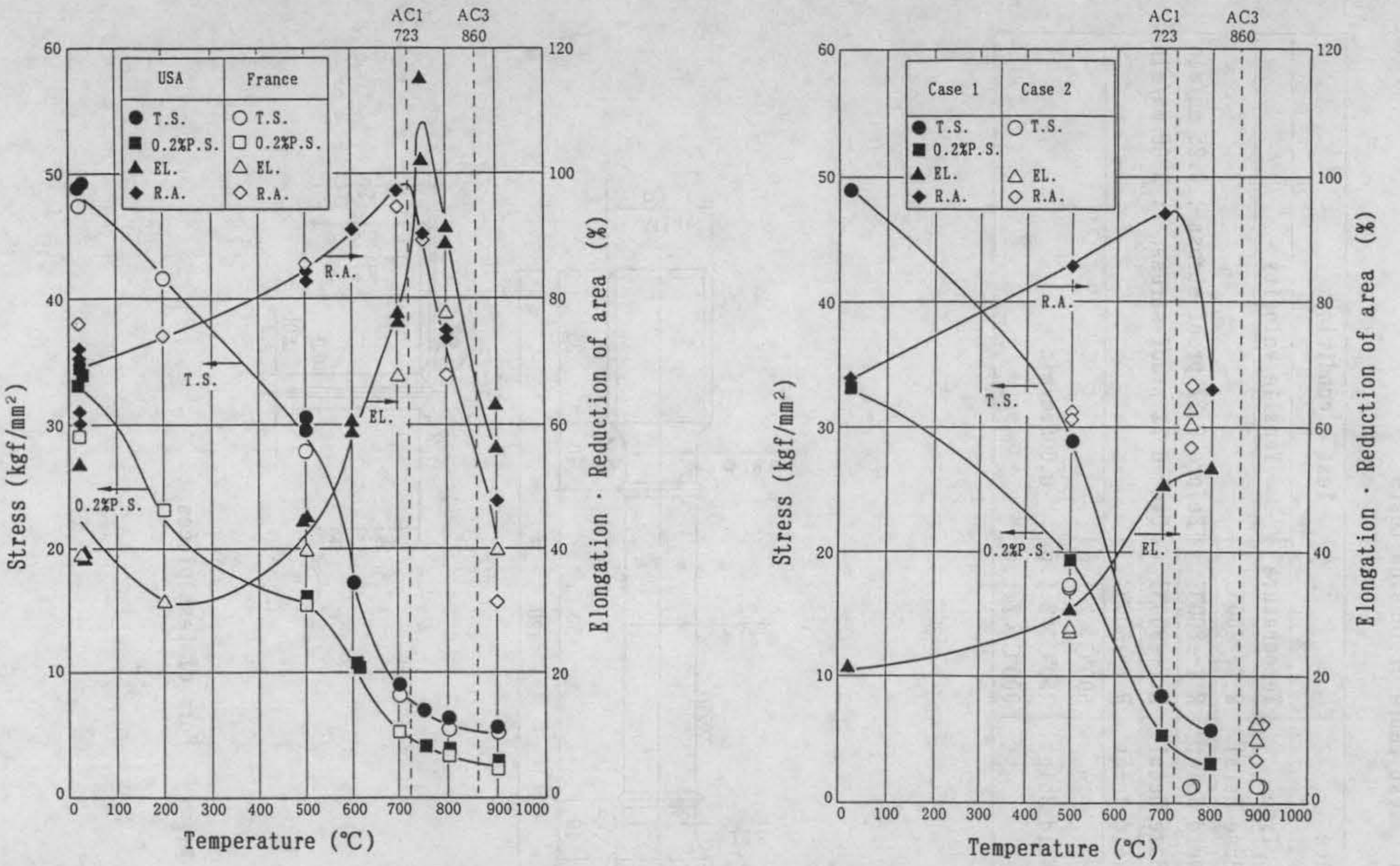


Fig.1 Form of test pieces



Base metal pieces (SA516 Gr.60)

Weld joint pieces (SA516 Gr.60)

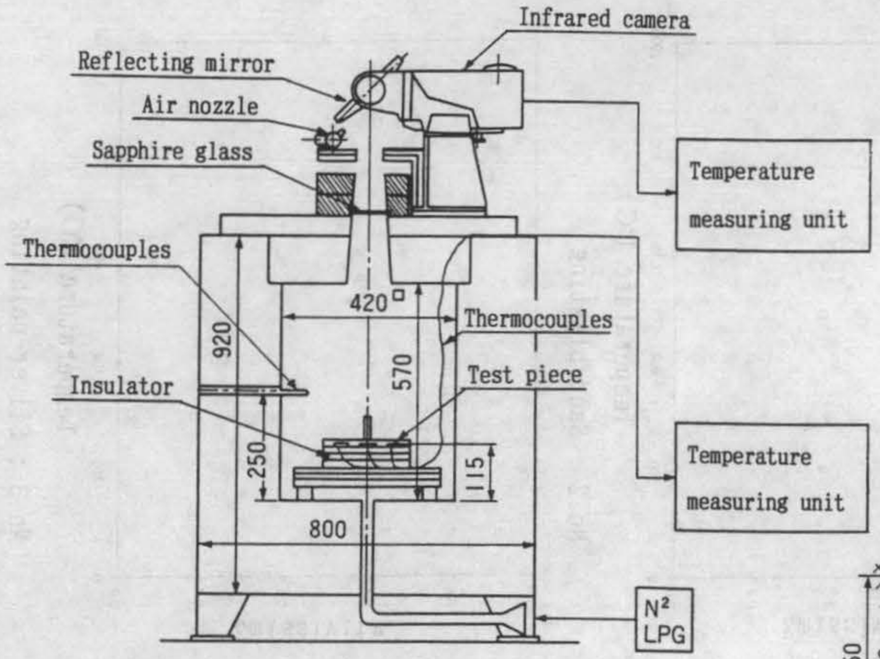
NOTE :
T.S. : Tensile strength
0.2%P.S. : 0.2% proof stress
EL. : Elongation
R.A. : Reduction of area

Case 1 : Tensile velocity is 0.25 mm/min
Case 2 : Tensile velocity is 0.005 mm/min

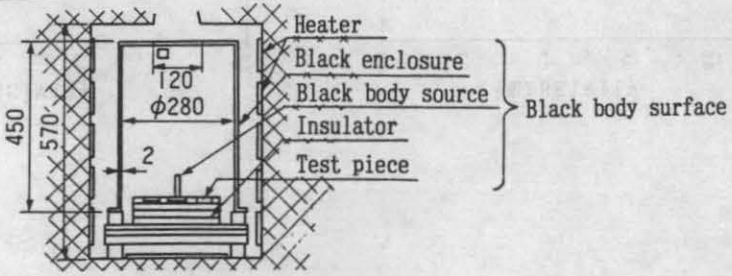
Fig.2 Strength data of structural material of 48Y-cylinder

Table 2 Test pieces of measuring emissivity

Base Metal	Surface transaction	No.
Carbon steel (SA516 Gr.60)	Oxidized film	1
	Sand-blasting	2
	Silver-painting	3

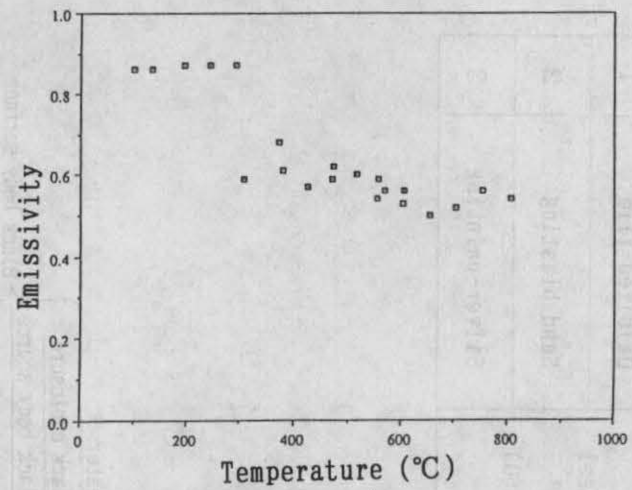


Furnace

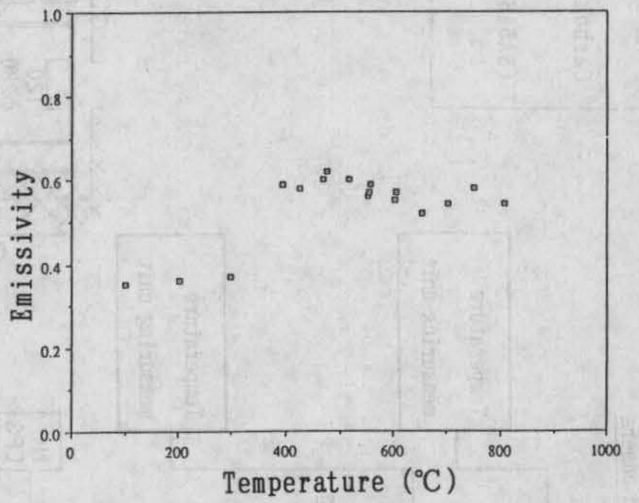


Arrangement of black enclosure in the furnace

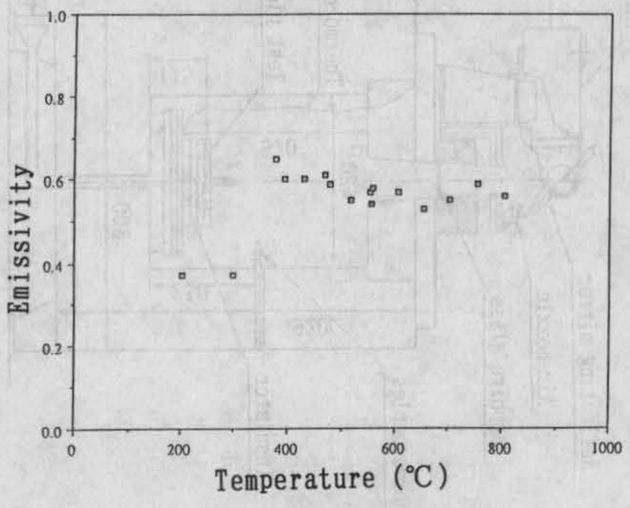
Fig.3 Equipments of emissivity measuring apparatus



No.1 : Oxidized film



No.2 : Sand-blasting



No.3 : Silver-painting

Fig.4 Emissivities of carbon steel

Session 29:

ANALYSIS METHODS AND TOOLS-II

Chairman : G. F. Hohnstreiter
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Development of Methodology for Certification of Type B Shipping Containers using Analytical and Testing Techniques*

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INTRODUCTION

The Analysis and Testing Group (WX-11) of the Design Engineering Division at Los Alamos National Laboratory (LANL) is developing methodology for designing and providing a basis for certification of Type B shipping containers. This methodology will include design, analysis, testing, fabrication, procurement, and obtaining certification of the Type B containers, allowing usage in support of the United States Department of Energy programs. While all aspects of the packaging development are included in this methodology, this paper focuses on the use of analysis and testing techniques for enhancing the design and providing a basis for certification. This methodology is based on concurrent engineering principles.

Multidisciplinary teams within LANL are responsible for the design and certification of specific Type B Radioactive Material Shipping Containers. These teams include personnel with the various backgrounds and areas of expertise required to support the design, testing, analysis and certification tasks. To demonstrate that a package can pass all the performance requirements, the design needs to be characterized as completely as possible. Understanding package responses to the various environments and how these responses influence the effectiveness of the packaging requires expertise in several disciplines. In addition to characterizing the shipping container designs, these multidisciplinary teams should be able to provide insight into improving new package designs.

BACKGROUND

The performance requirements for certification of Type B Radioactive Material Shipping Containers in the United States are specified in the Code of Federal Regulations, Part 71 (10 CFR 71), "Packaging and Transportation of Radioactive Materials." Testing and analyses, or a combination of testing and analyses, may be used to demonstrate compliance with the normal and hypothetical accident conditions specified in 10 CFR 71.

The regulations do not define the allowable structural or thermal damage a packaging may sustain, but instead use radiological criteria as measures of the acceptability of the design. The package response must be such that the packaging can (1) meet containment requirements, (2) keep external radiation levels within stated limits, and (3) ensure that a criticality event cannot occur. In the United States, a Safety Analysis for Packaging (SARP) is required for every package that is to be certified. The Nuclear Regulatory Commission has

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published SARP guidelines in Reg. Guide 7.9. The following sections discuss how the package design meets the requirements of 10 CFR 71:

1. General Discussion
2. Structural Evaluation
3. Thermal Evaluation
4. Containment Evaluation
5. Shielding Evaluation
6. Criticality Evaluation
7. Operating Procedures
8. Acceptance and Maintenance
9. Quality Assurance

ANALYSIS TECHNIQUES

Analysis of shipping containers serves several purposes. During the preliminary design phase, analysis provides necessary information on specific component design requirements. Analysis prior to testing helps identify areas of a structure where potential problems could arise during the testing. Pre-testing analysis also helps determine locations for instrumentation in order to optimize the data gathered during testing. Post-test analysis is used to understand the data obtained from the testing and helps to benchmark the analyses. Once an analytical model is benchmarked, design parameters, including component tolerances and material characteristics, can be varied in order to analyze how the design responds to the extremes of the environmental conditions. In some cases, when testing is impractical, analysis is the only method that will allow the engineer to confirm the acceptability of the design.

Computer modeling techniques used at LANL include the ABAQUS (Hibbitt et al. 1989) finite element analysis code (for analyses that will be used for certification), DYNA (Hallquist and Benson 1987), PRONTO (Taylor and Flanagan 1987), EXPLO (Jaeger and Vigil 1987), and other analysis and optimization programs. The ABAQUS finite element code is a commercial, benchmarked code capable of performing geometric and material nonlinear static and dynamic evaluations with fully coupled heat and stress analysis, large displacements and rotations, finite strain elastomers, and rigid surface contacts. The DYNA three-dimensional finite element code is capable of analyzing large deformation structural dynamic responses. The PRONTO 3D code includes nonlinear constitutive models and geometric nonlinearities resulting from large deformations, and is capable of providing dynamic impact analysis. EXPLO is a one-dimensional thermal analysis code which uses finite differences to calculate temperature fields. EXPLO can use temperature-dependent material properties including phase changes and multiple heat source terms with boundary conditions that include conduction, flux, radiation, and internal or external convection conditions.

TESTING

Structural and thermal testing is conducted to aid in the characterization and verification of Type B container designs. Testing allows the normal and hypothetical accident conditions specified in 10 CFR 71 to be simulated in a controlled environment.

Objectives of a test program can include: bench marking of analyses, environmental characterization, design margin determination, proof testing, initial damage determination for analyses, and confirming acceptability of individual package components. The information necessary to create a valid computer model and the tests required for certification are brought together with testing techniques and measurement capabilities. Field and laboratory tests are used to satisfy the test objectives. In some cases testing is the only method that will allow the engineer to confirm the acceptability of components that cannot be evaluated completely by analysis.

Los Alamos National Laboratory has a wide variety of laboratory and field testing capabilities that directly support package engineering teams. These capabilities include data acquisition/reduction, static and dynamic testing, environmental testing, and material characterization.

Extensive instrumentation and field portable data acquisition equipment are capable of measuring hundreds of channels of structural and thermal responses during actual transportation or laboratory testing. Instrumentation includes traditional transducer installations for strain, acceleration, displacement, pressure, and temperature measurements. Nontraditional instrumentation is developed for special applications such as heat flux measurement. Measurement recording systems include data loggers for measurements spanning several days or weeks, and fast transient recorders for measurements spanning several millisecond durations. Most systems provide real time output and hard copy data plots within minutes of test completion.

Laboratory simulations of transportation environments are achieved using vibration, shock, static, environmental and thermal test equipment. Vibration testing facilities include electrodynamic and servohydraulic test equipment with up to 36,000 pounds force capacity and frequency ranges from 0.1 to 3,000 Hz. Shock testing machines have capabilities up to 2,000 pounds and 5,000 g of acceleration. A 150-foot vertical tower provides the capability for drop testing objects up to 6000 pounds onto an "unyielding" target. Pneumatic and hydrostatic pressure testing is possible up to 100,000 psi. Static load test frames have compressive and tensile capacities up to 2,200,000 pounds of force. Cyclable thermal chambers with temperature ranges from -70 to 180 degrees Celsius and volumes up to 280 cubic feet are used to demonstrate design functionality at environmental extremes. One thermal chamber allows simultaneous altitude simulation up to 100,000 feet of elevation or controlled relative humidity between 5 and 95 percent. Capabilities for water spray and immersion testing exist. General leak test capabilities including both fixed and portable systems using pressure drop, pressure rise, or helium mass spectroscopy are available. A wind-shielded fire pit eight feet in diameter can sustain a fuel fire burn for up to two hours.

Material characterization facilities exist to generate data required to develop constitutive material models for use in analytical efforts. This ability allows material properties to be evaluated under the actual environmental conditions anticipated during transportation. The properties for nonstandard materials can be evaluated early in the design process to determine whether they are suitable for use and will enhance the container design.

Other capabilities relative to testing being investigated at Los Alamos include data recording packages and mock thermal loads which could be sealed inside containment vessels during testing. These would eliminate any extrinsic effects from electrical cables during testing.

METHODOLOGY

The methodology being developed at Los Alamos is based on principles of concurrent engineering. At the start of the program, people involved with the package design, certification, fabrication and use are brought together into a product development team. Although this methodology applies to the complete product development process, this paper is focusing on the design and certification steps emphasizing the iteration of analysis and testing techniques. The analysis and testing techniques discussed earlier are used concurrently to develop a complete understanding of how the package design responds to the environments defined in the regulations

The design of a packaging is broken down into four phases. These phases are: development of design constraints, conceptual design, preliminary design, and final design. Proceeding from one phase to the next does not preclude taking steps back and revisiting previous phases. The objective of this methodology is to eliminate "long loops" in the design process in favor of "short loops." By frequent iteration of analysis and testing, design changes can be made as determined necessary, rather than waiting until the process is nearly complete to initiate a major redesign.

The use of multidisciplinary teams should lead to higher quality and more innovative designs. A combination of mechanical and thermal analysis with structural and thermal testing activities and material evaluations are concurrently utilized to evaluate and verify Type B shipping container designs. A primary objective for an iterative approach to analysis and testing is to get the most out of each event. Both analysis and testing activities throughout the package development should represent a concurrent and iterative process leading to an understanding of the container design.

Each member of the product development team defines their requirements and needs at the beginning of the design phase. The team determines the wide range of packaging design constraints. The contents of the package as well as the performance requirements of 10 CFR 71 play an important role in determining the design constraints. In some cases the packaging is designed and certified for only one specific item. However, for more generally defined contents, this definition can be very difficult. The nature of the contents drives the package design. Contents that generate a great deal of heat require different design features than those that give off high levels of radiation. Some of the questions raised while determining design constraints might include: What are the overall size requirements for the package? Are these size requirements specific to the size of the facilities using the package? Are there special containment, shielding or criticality requirements? All these issues require a diverse team working together to improve the package design.

After the design constraints are defined, a conceptual design of the packaging is developed. Conceptual design analysis activities evaluate an initial geometry by which test hardware can be procured. Initial analysis is used to get an idea of how the preliminary design will respond to the different environments. Concerns generated during this initial analysis of the conceptual design may lead to the team deciding to reevaluate the design constraints before proceeding to the preliminary design.

Once the product team has approved the conceptual design of the packaging, the preliminary design phase is initiated. During the preliminary design phase, further analysis of the packaging design indicates regions where instrumentation is to be installed in order to benchmark the analyses, and suggests possible weaknesses in the design that may require further detailed analysis, evaluation testing or design modification. Testing during the preliminary design phase is used to verify computer models, provide feedback concerning areas in the design of particular interest, determine the boundary conditions for subsequent analysis (e.g. initial damage deformation from a crush input), demonstrate compliance with 10 CFR 71, and provide an empirical feel for how the container will respond to the normal and accident transportation environments defined in the regulations.

Analysis prior to testing is used to gain maximum knowledge from testing and to give a basis for the data required to benchmark the analyses used for certification. In order to obtain usable and optimal data from testing, predicted levels of strain, acceleration, displacement, or temperature are needed. The prediction of these levels is done by analysis, and this information is used to select types of instrumentation to use in order to gather usable data.

Results from initial testing can provide boundary conditions for subsequent analysis and modeling. For example, deformation and other damage observed (measured) during initial testing are used to define initial boundary conditions for shielding and criticality analyses. This in turn allows a better evaluation of shielding effectiveness and criticality implications. Post-test analysis is used to interpret test results.

Field testing is used to characterize the transportation environments defined in 10 CFR 71. For example, an acceleration measurement obtained from the simulated container contents during impact from the 30-foot drop defines the actual time history acceleration pulse imparted to the contents after mitigation by the external package structure. This information can lead to optimizing the support structure to prevent problems associated with other design requirements.

Laboratory testing can be used to simulate transportation specifications or reproduce actual measured field data. This simulation can take place at a system (the whole container) or component (support flange weld) level. Laboratory testing allows a more detailed evaluation of the environmental effects on the packaging components or the overall system. The uncertainty associated with the ambient test conditions can be controlled in a laboratory.

Limited information is available on the properties of the materials used in various container designs. The majority of the information is usually specified at a nominal ambient temperature. Since most material properties are functions of temperature, material modeling becomes more difficult as the temperature of the container varies. LANL is testing several materials and developing constitutive relationships that can be input to the various computer codes for material properties such as thermal conductivity, Young's modulus, and other parameters that are either temperature or strain rate dependent.

Subsequent analysis using a verified model is used to perform parameter studies. The parameter studies evaluate variations in material properties, dimensional tolerances, and environmental inputs. Using analysis, these studies can be accomplished more quickly, and in some cases with less cost, than is possible by building and testing hardware. Any unfavorable or marginal results can be evaluated through subsequent testing.

The concurrent engineering process of analysis coupled with testing is especially useful in determining design margin. The initial analysis suggests locations of high stress for specific evaluation during the initial testing. In turn, the test results can be used to further verify the model. Refinement of the mesh allows the stress state of the entire structure to be determined at specific locations. Through an iteration process, any level of design margin can be obtained.

Once analysis and testing has been completed on the preliminary design, and the design has been charactized, the final design is issued. In some cases, proof testing or further analysis of the final design may be required for certification.

Package proof testing generally demonstrates that a container design meets regulatory requirements. While this works, the proposed concurrent methodology allows for a better understanding of the container's response to postulated transportation environments and allows a determination of the design margin. In effect, the methodology answers the question, "Is the container's weakest point at 50% or 95% of yield?" A totally uninstrumented test or a test without instrumentation in the proper locations may not answer this question. An accident environment that slightly exceeds the regulatory requirement (or worse yet, just the test-to-test variation) might possibly lead to a release of radioactive material.

An example of the concurrent engineering approach with respect to one component of a package design is demonstrated with the selection and certification of a seal design. Once the package design constraints are set, a seal design is proposed. Initial analysis of the conceptual design is used to select the sealing material. This selection takes into consideration effects the contents may have, both from the radiation and the heat given off, temperatures the seals will be exposed to during normal conditions of transport and during the hypothetical accident fire, and the level of containment required. Thermal testing provides a temperature distribution in the region of the seal through adjacent measurements. Subsequent leak testing verifies that the seal remains leak tight after being exposed to the thermal environments. Analysis of the temperature distribution during the fire indicates that the O-ring seal remains below the material thermal limitations during the fuel fire environment and that no gaps form as a result of thermal expansion allowing loss of the precompression load on the seals.

CONCLUSIONS

The use of multidisciplinary teams to develop Type B shipping containers improves the quality and reliability of these reusable packagings. Including the people involved in all aspects of the design, certification and use of the package leads to more innovative, user-friendly containers. Concurrent use of testing and analysis allows engineers to more fully characterize a shipping container's responses to the environments given in the regulations, and provides a strong basis for certification.

Pre-analysis of a design gives valuable insight into information the engineer needs to obtain during testing. Testing provides benchmarking for the analysis methods used. Once the analyses are benchmarked, they can be used to develop an understanding of how the package might respond to conditions at environmental or design extremes. For various reasons: cost, time restraints, material availability, or the types of information needed, either testing or analysis of the design may be impractical. Post-test analysis is used to interpret test results and determine accuracy of the data. The ability to determine material properties of new materials should allow designers more flexibility in the choices of materials they utilize in their designs. Proof tests of the overall design for certification are done where required .

One bit of engineering folk lore has it that everyone believes the experiment but the experimenter, and no one believes the analysis but the analyst. The proposed concurrent engineering methodology combines the best of both approaches. By making the analysis and testing (experiment) a concurrent activity, the believability of the experiment is combined with the confidence in the analysis.

The combination of the input and output of these efforts should provide a general methodology that designers of Type B radioactive material shipping containers can utilize to optimize and certify their designs.

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