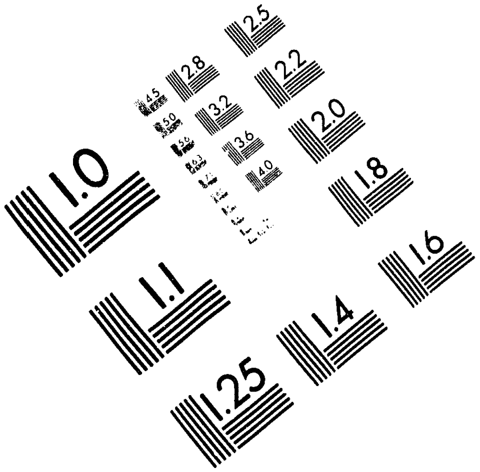

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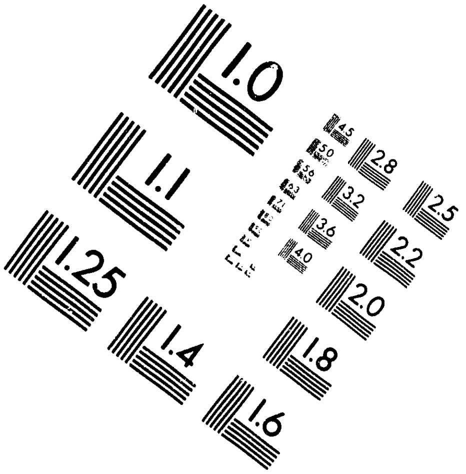

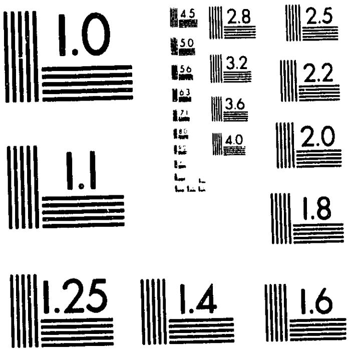

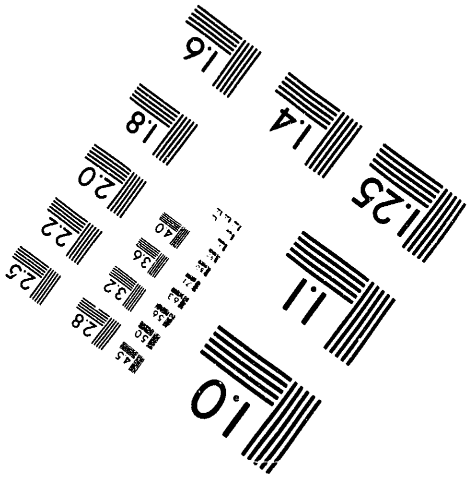

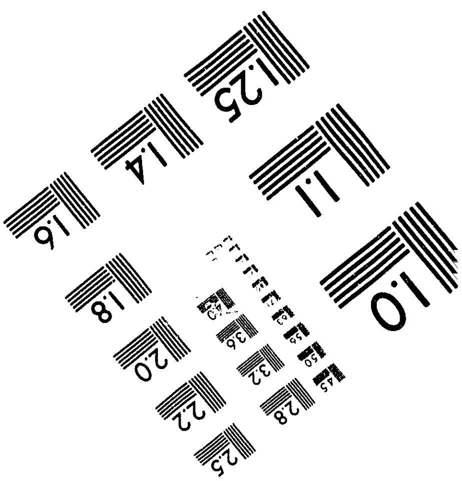

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SYSTEM RESPONSE OF A DOE DEFENSE PROGRAM PACKAGE IN A TRANSPORTATION ACCIDENT ENVIRONMENT*

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ABSTRACT

The system response in a transportation accident environment is an element to be considered in an overall Transportation System Risk Assessment (TSRA) framework. The system response analysis uses the accident conditions and the subsequent accident progression analysis to develop the accident source term, which in turn, is used in the consequence analysis. This paper proposes a methodology for the preparation of the system response aspect of the TSRA.

I. INTRODUCTION

The U.S. Department of energy (DOE) is responsible for the transportation of nuclear materials, components and weapons from manufacture until they are released to the U.S. Department of Defense (DOD). DOE is also responsible for the transportation of nuclear materials, components and weapons from the moment they are returned from DOD until final dismantling and/or disposal. DOE Order 5610.1 Section 7.b[1] requires that contents must be packaged and transported to provide a level of safety comparable to that provided by the packaging and shipment, in accordance with applicable Federal regulations, of other radioactive and explosive material. Title 10 of the Code of Federal Regulations, Part 71, Section 73 (10 CFR71.73)[2] established the specific sequences of hypothetical accident conditions to which transportation packages with fissile material contents or greater than Type A quantities of radioactive material contents must be tested. These requirements may be satisfied either through analysis and/or by performance tests and once they are satisfied, the package is certified for transportation. For those Defense Program (DP) packages that fail to meet these requirements, a Transportation System Risk Assessment (TSRA) must be prepared under an authorization process administered by the DOE Albuquerque Field Office (DOE/AL).[3]

As part of the Lawrence Livermore National Laboratory's (LLNL) technical assistance to DOE/AL, LLNL is currently assisting DOE/AL in the preparation of Safety Guide 200 Series. The Safety Guide 200 Series is a succession of documents which provides guidance to preparers of the TSRA. A specific safety guide within the series focuses on the system response. An overview of the TSRA concept and methodology is given in a separate paper by Brumburgh.[4] This paper discusses a proposed methodology for the system response aspect of TSRA. For the purposes of the Safety Guide 200 Series, the system whose response to the accident conditions is being examined, is defined as the transporter, the enclosed packaging, and its contents. The packaging and its contents constitute the package. DOE currently uses highway shipments and air shipments to transport Defense Program packages. This paper will discuss only the highway mode of transportation although this methodology could be applied to air shipments.

Highway shipments of nuclear material are accomplished in DOE owned and operated armored tractor trailers called "Safe Secure Trailers" (SST) equipped with safeguard systems. The system response of a DP package in a transportation accident environment should therefore consider the response of the SST together with its cargo during a hypothetical accident. Three categories of loading scenarios—mechanical loads, thermal loads, and combination load should be addressed in the assessment of the system responses.

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II. SYSTEM RESPONSE TO MECHANICAL LOADS

Mechanical loads may consists of impact, crush, and puncture. To begin the system response analysis, general information is required on the system dimensions, materials of construction, and material classification.

A. Material Considerations

The structural properties of the materials used in the design and construction of the system under consideration should be known thoroughly. This includes material mechanical and physical properties, their corrosion resistance, how it was fabricated, and its fracture toughness.

With regard to the mechanical and physical properties of materials, the following are a partial list of properties need to be examined:

1. minimum yield strength
2. minimum tensile strength
3. percentage elongation
4. percentage reduction of area
5. Young's modulus
6. plastic modulus
7. Poisson's ratio
8. fatigue curves
9. creep threshold temperature corresponding to 10^6 hours creep rupture life
10. fracture toughness
11. coefficient of thermal expansion
12. chemical composition ranges
13. heat treatment
14. density
15. chemical composition
16. heat capacity
17. thermal conductivity
18. melting temperature
19. emissivity
20. stress-strain curve

With respect to *corrosion resistance*, the following information must be determined by the preparer: a) A list of the construction materials of system components that are exposed to corrosive or other aggressive environments, b) A description of material compatibility with the containment or radiolytic products to which the materials may be exposed, and c) An assessment of the degree to which the material or structural properties of the material are affected by exposure to the corrodants. This may be reflected by reductions in design stress, fatigue limits, or fracture toughness.

As for material *fracture resistance*, austenitic stainless steels (gamma iron phase) do not exhibit a transition from ductile to brittle behavior with temperature. They normally retain their ductility and toughness at extremely low temperatures. However, austenitic stainless steels are subject to stress corrosion cracking and intergranular corrosion and must be protected from contaminants and environments that promote cracking and corrosion. Test data and service experience indicate that sensitized stainless steel is significantly more susceptible to stress corrosion cracking. Because excessive cold working in austenitic stainless steels can render this material more susceptible to stress corrosion cracking, the cracking must be controlled by placing an upper limit on the yield strength. On the other hand, ferritic steels (alpha iron phase) exhibit a transition with temperature from ductile to brittle behavior. It is essential that the steel at the lowest service temperature exhibit a toughness well beyond its Nil Ductility Transition Temperature (NDTT). The required margin between the lowest service temperature and the maximum allowable NDTT depends upon the thickness of the material.

B. Hypothetical Accident Conditions

The assessment of the system response to mechanical loads may be by analysis, prototype testing, model testing, or comparison with a similar system.

1. Analysis. Three analysis methods have commonly been used for impact evaluations: quasi-static, dynamic lumped-parameter, and dynamic finite element. Each method or some combination of them can be used to predict the response of a system under consideration to an impact or crush load under certain conditions. The dynamic analysis method can more accurately predict response under impact loading since this loading produces dynamic response of the system.

The quasi-static method is based on D'Alembert's principle for substituting equivalent static forces for inertial forces created by impact. This method assumes constant, homogeneous deceleration and cannot capture dynamic response. Also, restrictive assumptions must be applied to capture secondary impact, if any. It is not recommended for analyzing complex impact situations. In applying this method, a deceleration force is calculated by assuming that all of the kinetic energy is absorbed by the system and that the deceleration is constant. The acceptability of this method is predicated on several factors. First, the loading rate to the system must be slow enough to reduce the probability of dynamic amplification. Second, since even for a relatively slow loading rate, an appropriate dynamic amplification factor should be applied to the results. Third, since there are too many uncertainties in this method, there should be a large margin of safety in the final response estimation if this method is used.

The specific dynamic lumped parameter method combines simplicity in modeling with the ability to analyze the dynamic response of the system as a result of an impact. In addition, the method can be formulated to analyze the rigid-body rotation which can occur as a result of impact in certain directions. Overall system response can be determined as well as the resulting major stresses. Stress recovery assumptions can become very restrictive if calculation of detailed stress states is attempted. The dynamic lumped parameter method may be used for confirmatory analyses for impact loading. It is simple to use and is not as complex as 3-D dynamic analysis. However, due to the simplicity of the model, it cannot accurately predict local stresses or local deformations.

A dynamic finite element analysis should be performed in order to obtain detailed stress and strain states, accurately model nonlinear and deformation behavior and crush events of the system and its interactions. In this method, each component can be modeled separately, and stresses and deformation amount can be calculated directly during the analysis. While they can be expensive and time consuming, dynamic finite element analysis methods can provide the most accurate and detailed estimates of subjects response to impact loads. The dynamic finite element method should be used for reviewing of any components that have predicted stresses and strains well into the plastic range, large deformation, complex geometry, or complex loading conditions.

2. Prototype Testing. Test method, procedures, and target that were used should be described. If the system tested is not identical in all respects to the system described in the application, the differences should be explained to show that these differences are not important or have a very minor effect on the test results. All analyses performed should be verified to establish the system configuration and orientation for the testing.

Materials used as substitutes for the radioactive contents during the tests should be analyzed to verify that this substitution would not affect the test results. The effects of internal decay heat and pressure buildup must be considered if these effects had arisen with the actual loading.

The damage caused by the impact and the results of any quantitative measurements that were made as well as both interior and exterior damage should be included. Photographs of the damaged system should be provided as well as analyses performed to demonstrate that the use of testing results in deriving other relevant quantities.

3. Model Testing. The model description and the detailed drawings that show its dimensions and materials of construction should be included. The dimensional tolerances to which the model was fabricated, and the comparison of these to the tolerances that are used for the prototype should also be included. All analyses performed which relate the scale model to the prototype for the test conditions should be provided.

Appropriate scaling laws to assure the correctness of the scaled model test in relationship to the actual size and the correlation method used and the amount of damage done to the model with damage to a prototype should be analyzed. Model testing should be performed primarily to benchmark computer codes used to analyze the prototype.

4. Comparison with similar system. A similar system and arrangements should be compared whenever available. The following information should be included:

(1) the dimensions, materials, and configurations of both systems;
(2) the overall weight of both systems;
(3) the weight and form of the contents of both systems; and
(4) the contents arrangements.

The comparison should demonstrate:

(1) that the system will have a similar response to the specified tests;
(2) that the forces acting on all vital systems and components are equal to the tested system;
(3) that the contents interaction exhibits similar characteristics and will have similar responses to the specified tests.

III. SYSTEM RESPONSE TO THERMAL LOADS

The system thermal response assessment should determine all critical components temperatures, possible pressure build-up for various conditions, and any phase changes or thermal degradation that could occur. The thermal results are used to evaluate thermal stresses, temperature effects on material properties, and reduction in containment or shielding capabilities of its contents caused by material phase changes or degradation.

A. Material Considerations

As listed under Mechanical Loads, all mechanical and physical properties of materials need to be examined to make sure that they cover the temperature range of applications. As for non-structural materials such as thermal coatings, lead shielding, and neutron shielding, information or references should be included in order to provide sufficient information to perform a confirmatory analysis, if necessary.

B. Hypothetical Accident Conditions

Analytical methods may include scoping calculations and numerical simulations using thermal computer codes. Scoping calculations may be performed during the initial stage of analysis to provide an overview of the thermal condition and identify the critical areas for concentrating the work efforts. Thermal computer codes are used to verify thermal evaluation for more complex heat transfer situations. It is important to select a thermal code that has been well benchmarked and that interfaces with a structural code in order to perform thermal stress analysis. All heat sources and sinks should be identified. When contents vary or their heat absorption capability cannot be ensured, they should not be included in the model as a heat sink but included only as a heat source.

If tests are performed, the preparer should state clearly the specific objectives of the test and the procedures used to correlate the test data to the thermal environment.

IV. SYSTEM RESPONSE TO COMBINATION LOADS

Concurrent mechanical and thermal loads may produce a more severe loading than if only one type of loading were presented or loads were applied to the system in a sequential manner. The combination loads require an analysis method that is capable of handling the coupled effect the loading would have on the system components. The preparer should examine each and every accident state carefully to determine whether loads were applied in a sequential manner or they are separated by sufficiently long duration so that a sequential loading analysis can be safely assumed. When loads produced by the accident are close together such that one could easily have influence on the other load and vise versa, a coupled analysis is definitely required. Some of the commercially available computer codes are written specifically to examine the coupled thermal and mechanical loads on a structure component.

V. SUMMARY

A methodology on how to prepare the system response aspect of a DOE package in a transportation accident environment has been proposed. The preparer should examine system response to mechanical loads, to thermal loads, and to combination loads. The paper highlights some of the important issues when preparing the system response portion of the Transportation System Risk Assessment.

REFERENCES

1. DOE Order 5610.10, "Packaging and Transporting of Nuclear Explosives, Nuclear Components, and Special Assemblies," Office of Military Applications, September 11, 1979.

2. Title 10 Code of Federal Regulations Part 71, "Packaging and Transportation of Radioactive Material (10 CFR 71)", Office of the Federal Register, revised as of January 1, 1992.

3. DOE/AL Supplemental Directive 5610.1, Rev. 1, "Packaging and Transporting of Components and Special Assemblies Associated with the Nuclear Weapons Program," September 28, 1992.

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