U.S. NRC Containment Integrity Programs

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Abstract

The U. S. Nuclear Regulatory Commission (NRC) is sponsoring a set of programs whose objectives are to provide the data base required for the qualification of methods for predicting the response of containment buildings for light water reactors (LWR) during severe accidents (those beyond design basis events) and extreme earthquakes. This set of programs is examining the modes of containment failure that result in the release of radioactive materials beyond the containment boundary. These modes include structural failure of the containment building, leakage through or past the penetrations (electrical or mechanical), failure of containment isolation systems, or failure of the base mat by the molten reactor core. The first two modes of failure, which are being studied by Sandia National Laboratories (SNL)*, are discussed in this paper.

1. Introduction

Since the accident at Unit 2 at Three Mile Island, a major effort in safety studies in the United States has been directed toward determining the potential risk of hypothetical severe accidents and extreme environments. One facet of this work has been directed to a study of the containments of LWRs, which are the last barriers designed to prevent the release of radioactive materials. The mode, location and timing of the failure (excessive leakage) of the containment system is required in performing risk studies, and in emergency preparedness planning, siting of power plants, and evaluation of accident mitigation strategies. The containment integrity programs are providing this information. The NRC-funded programs are examining the performance of the entire containment system when subjected to loadings due to either a severe accident or an extreme earthquake. The work on severe accidents has been funded for several years, while the work on earthquake loading of containments is expected to begin in 1986. A brief summary of the overall effort is given here, while details are given in companion papers [1-4] and in [5].

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1.1 Background

U. S. containment buildings and penetrations are designed to procedures established by the American Society of Mechanical Engineers (ASME) and the American Concrete Institute (ACI). The loadings, which are specified by the owner and approved by the NRC, include design basis accident conditions, earthquakes, tornadoes, and combinations of these loadings. However, loadings due to severe accidents (those beyond Class VIII) or, for example, earthquakes more extreme than the safe shutdown earthquake (SSE) are not considered. Although the containment has a structural capacity for loads beyond the design conditions, estimation of this capacity is not straightforward, since the design is based on essentially elastic behavior, and nonlinear behavior will likely occur before the containment's ultimate capacity is reached.

Failure during an accident of the containment system - that is release of radioactive materials above a specified value - may occur by: (i) failure of the isolation system (valves) to close or to seat properly and thus leak excessively, (ii) leakage past the sealing surfaces in operable mechanical penetrations or in the electrical penetration assemblies, (iii) structural failure of the penetrations themselves (iv) structural failure of the steel shell (steel containments) or the steel liner (concrete containments) and (v) failure of the concrete base mat (including the liner in the base mat) due to direct attack by the molten core. This paper discusses the programs that are examining items (ii) to (iv). This work is being conducted by Sandia for the NRC. Previous work is reported in [6]. The work on isolation systems is being examined by Idaho National Engineering Laboratory while the work on molten-core concrete interaction is conducted by SNL [7].

1.2 Objectives of the Programs

The overall objective of Sandia's work is to develop a methodology that will permit the estimation of the leakage of a given containment when subjected to various severe accidents. To reach this objective, experiments are being conducted on models of containments, full- and reduced-scale penetration assemblies, and sealing materials. The results will also be used to qualify existing methods that will be used to calculate the performance of the containment system.

1.3 Program Activities

The overall activities are divided into several subprograms that each concentrate on a particular aspect of the problem. These subprograms cover (i) the testing of scale containment models, (ii) the testing of mechanical penetrations and sealing materials, (iii) the testing of electrical penetration assemblies, (iv) analyses of the containment building and the mechanical and electrical penetrations, and (v) development of a methodology for predicting performance.

2. Containment Model Testing

In the early phases of the model-testing program it was decided to test models of steel containments (those typical for a PWR ice condenser or BWR MK-III), reinforced-concrete containments (large dry) and prestressed-concrete containments (large dry). The loadings that were to be considered are quasi-static and dynamic internal overpressurization and earthquakes. Currently, plans do not include the testing of a prestressed containment model. Rather, separate effects tests on prestressed concrete elements will be conducted. Results of these tests and the results of the reinforced concrete containment model test will be used to validate methods to calculate the performance of prestressed containments. The work to date has concentrated on the quasi-static overpressurization load. In these tests pneumatic (nitrogen gas) pressure is used because of the requirement for measuring leakage from the models. Planning for performing tests considering earthquake loads is expected to begin in 1986, while the schedule for testing with dynamic overpressurization have not been formulated.

The tests are conducted at a remote site due to the safety hazards associated with pneumatic testing. The pressure is increased in the model in discrete steps through a remotely controlled system. Extensive instrumentation consisting of strain gages, displacement transducers, pressure gages, thermocouples and photographic coverage provides bench mark data for qualifying computer codes. Four tests [8] have been conducted on 1:32 steel models. Two of these models were "clean" shells consisting of a cylindrical shell with a hemispherical dome. The third model included ring stiffeners, while the fourth model was a "clean" shell with a nonoperating (i.e., no seals - but rather a welded joint) equipment hatch and personnel lock. A 1:8-scale steel model was designed according to the ASME code for a design pressure of 40 psig. This model included ring stiffeners and several penetrations, including two equipment hatches with an O-ring seal, and a constrained pipe penetration. Testing of this model was completed in November 1984 [1,3,4].

Currently, a 1:6 reinforced concrete containment model is being designed [9]. Fabrication of this model is scheduled to begin in the third quarter of 1985. This model will include a steel liner and several penetrations, including operating equipment hatches.

Results of the tests on the 1:32 steel models are given in [8,10], while the comparison of the results with analysis for the 1:8-steel model is given in [3,4].

3. Penetration Testing

Testing of three full-size electrical penetration assemblies (EPAs) will begin shortly. Steam pressure, following the envelope of the calculated environments for different severe accident scenarios for PWRs and BWRs, will be applied to the EPAs in a specially designed test facility. Leakage, temperature gradient along the assembly, and electrical continuity will be measured [11].

For the mechanical penetrations, a background study that characterized the various penetration designs was completed. This study, combined with preliminary analyses, resulted in the decision that the following penetrations will be tested (either scale model or full size): equipment hatch (both pressure seating and unseating designs), personnel lock, drywell head of a BWR MK-I or MK-II, and a piping expansion bellows. The equipment hatches, because of the shell penetration interaction, are being tested in the scale containment models. In addition, numerous tests on sealing materials and geometries (e.g., O-rings made from silicone rubber) are also in progress. Details of the program, including loading conditions, are given in [2].

4. Analyses

Throughout the life of the program, structural analyses have been performed to provide insight for the selection and design of test specimens. For example, analyses of penetrations provide guidance as to which have the greatest potential to leak. In addition, detailed pretest calculations using finite element methods, including three-dimensional models, have been performed of the 1:32 and 1:8-scale steel containments. The results were used in the selection and placement of instrumentation. Also in the conduct of the test, actual experimental data were compared, in real time, against calculated values to determine if the instrumentation was yielding reasonable values [4]. Details of the analyses and comparisons are given in [3,8,10,12].

5. Methodology Development

The results of the experiments of scale containment models and on the mechanical penetrations will be used to qualify existing structural computer codes. No new codes will be developed, although minor modifications may be made to existing codes. These validated codes may then be used to evaluate full-size containments. In regard to leakage, the test results of the sealing materials and large-scale penetrations will be used to develop a method which will permit the estimation of leakage by a seal, given the temperature and pressure conditions and the opening or rotation of the joint. No existing methods have been identified. It is anticipated that an essentially empirical method will be developed, since the magnitude of the uncertainties precludes the development of an accurate analytical approach.

6. Coordination Activities

In addition to the active coordination of the research between the various NRC-sponsored programs, results of the work have been discussed with the Electric Power Research Institute (EPRI) and with foreign groups performing containment research.

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