The High Flux Isotope Reactor Oak Ridge National Laboratory Seismic, High Wind, Tornado, and Probabilistic Risk Assessments

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INTRODUCTION

The High Flux Isotope Reactor (HFIR) is a high-power density research reactor operating to a maximum of 85 MW (th). The high thermal neutron flux achieved in the reactor is utilized to produce isotopes of transuranic elements and to perform neutron scattering research.

In late 1986, an effort was initiated to evaluate the effects of neutron radiation on the integrity of the HFIR reactor vessel. Shortly thereafter a general reassessment of the design and operation of the facility was initiated under the direction of the U.S. Department of Energy (DOE). HFIR was designed, constructed, and began operation more than 20 years ago. During this period, the nuclear community developed and implemented a large body of codes and practices that were not part of this facility design. EQE was selected to perform deterministic, seismic, high wind, and tornado analyses, and support the probabilistic risk assessments utilizing its earthquake experience data base and evaluation methods developed to assess the seismic adequacy of vintage facilities.

The reassessment was divided into two phases. Phase I consisted of an analysis and seismic evaluation of primary structures and reactor systems. Phase II consists of tornado evaluations of primary structures and systems and seismic and tornado evaluations of confinement systems and electrical power and cooling systems and structures. In addition an external events scoping study and fragilities were developed for the probabilistic risk assessment (PRA). The PRA will provide risk information to the decision process regarding upgrades to the facility during its remaining life.

Phase I - Assessment of Reactor Structures and Systems

The HFIR is located on the DOE Oak Ridge, Tennessee Reservation. The local geology and site foundation are on a stiff clay shale with an average twenty-foot overburden of organic top soil. The seismicity of the Reservation has been studied extensively and an evaluation earthquake anchored at 0.15g horizontal peak ground acceleration was selected for the deterministic reevaluation. High wind and tornado criteria specified a 150 mile per hour wind or tornado velocity.

REACTOR STRUCTURES

The Reactor Building, which houses the reactor, coolant system, equipment, and experiment rooms, consists of two major structural systems: a massive reinforced concrete substructure and a lightly reinforced concrete-frame superstructure. EQE utilized a large multi-degree of freedom, three-dimensional finite element model of the building. The reactor bay superstructure was modeled in considerable detail to capture significant features of the irregular containment boundary while the substructure analysis utilized simplified and conservative shear beam and rigid diaphragm models. Response spectrum analyses were performed on a Cray computer system for the two horizontal and the vertical input directions, assuming that a combination of dead and seismic loads would affect the shear walls, roof beams, roof slab, and columns.

Response analyses results indicated that significant cracking of the upper structure walls and framing of the superstructure would occur. A model (Figure 1) including effects of cracked concrete sections identified from the evaluation of the uncracked model was utilized to predict the performance of the cracked concrete structure. The analyses indicated sufficient seismic margins for all structural elements to preclude collapse and predicted no foundation problems.

The tornado-wind evaluation assumed the simultaneous occurrence of three events: high-velocity (150 mph) wind loading, pressure differential, and tornado missile impact. Behavioral aspects of the evaluation event were derived from site-specific tornado history and topography. Static analyses were performed to simulate the direct wind and differential pressure load on the reactor building model.

REACTOR VESSEL AND PRIMARY COOLANT SYSTEM

Two finite element models were constructed for the seismic evaluation of the primary coolant system. The first was a large multi-degree of freedom three-dimensional plate model of the reactor vessel (Figure 2). This model was developed to provide a precise stiffness and force distribution within the irradiated vessel. The second model was an equivalent beam model of the reactor vessel, primary coolant piping, and four pump and heat exchanger cell loops (Figure 3). As with the Reactor Building, analyses were performed on the Cray system model, including representations of piping and supports, reactor vessel and supports, control rods and support frame, neutron beam tubes, and heat exchanger cell components. Frequency responses from 1 Hz to 33 Hz were calculated. The primary loop model was also analyzed for gravity, thermal, and pressure load cases.

Results of the analysis indicated that the as-designed configuration contained adequate capacity to resist the evaluation seismic load. Seismic deflections in the piping system were, however, incompatible with clearances and seals and modifications were designed by EQE for upgrade of the primary system.

REACTOR INTERNALS

The HFIR reactor core has an exceptionally high power density and high peak thermal neutron flux. The design of the control rod and scram system is unusually rapid-acting and reactor shutdown is achieved in a fraction of a second. The design involves several complex mechanisms with close tolerances. Therefore, a detailed evaluation of the seismic performance of the core internals and control mechanism was performed.

The HFIR reactor internal support structure consists of two concentric cylinders bolted to the central cylindrical fuel and reflector support sleeve assembly. The internal structures were represented as lumped massed models and equivalent beam elements. Seismic displacements were determined to be well below allowable clearances, precluding contact between components. Seismic load margins for support assembly connections were determined to be acceptable. A shell finite element model of the scram control plates was also developed. These analyses also verified allowable clearances for the control plates under seismic load.

WALKDOWN OF PRIMARY SYSTEM AND APPENDAGES

The EQE walkdown consisted of a detailed review of the primary coolant pressure boundary, active components, and the emergency coolant pump and DC power supply system. Also included was an assessment of the reactor pool inventory isolation and control capability. The walkdown utilized the EQE earthquake experience data base methodology supplemented with results of the primary coolant loop finite element analysis.

Included in the walkdown was a review for potential seismic interaction hazards. Seismic interaction is typically caused by falling, overturning, or deflection of non-seismically designed components, resulting in impact with essential components such as instrumentation, electrical equipment, or pressure boundary appurtenances. Interaction hazards involving block walls, lead shielding, test equipment, and other inadequately anchored components were identified, mostly on the ground floor. In addition potential seismic interactions involving water spray, piping, and line deflections were identified. In most instances modifications were recommended and upgrades designed by EQE. A review of the reactor pool cleaning valves, pool seals, and pressure boundary tubing was also conducted as part of the walkdown.

MODIFICATION DESIGNS

EQE designed modifications for the primary coolant system piping to reduce seismic displacements and thereby protect primary system pressure seals and improve support to small diameter pressure boundary appurtenances. Additional designs were prepared to protect primary system pressure boundary or active component functions. These included bracing to large unsupported spans of unreinforced masonry, restraints to valves to preclude pounding damage, and restraints to non-safety piping systems to preclude water spray onto critical electrical components.

STACK ANALYSIS

EQE assessed the capacity of the 250-foot exhaust stack to resist the criteria earthquake and wind loads. The main concern was that the stack would collapse onto the primary containment system. EQE analyzed this reinforced concrete tapered structure with a two-dimensional model equivalent beam elements representing the physical properties of the outer shell. The analysis considered bending stress capacity of the stack shell, shear capacities, stack overturning resistance, soil bearing capacity, and foundation footing capacity. Findings indicated that under the criteria loads, collapse of the stack is probable 120 feet above the base. Such a collapse would not reach the Reactor Building.

Phase II - Confinement, Electrical and Cooling Systems and PRA

Phase II tasks have been recently completed or are ongoing. Areas addressed include the following:

SEISMIC/TORNADO ASSESSMENT OF ELECTRICAL BUILDING, CONTROL BUILDING, AND WATER WING

The HFIR facility also houses key support equipment and systems in three low-rise concrete and unreinforced masonry buildings. Seismic, high wind, and tornado missile evaluations were preformed for these buildings. Static evaluation methods were employed to evaluate their structural capacities. Under evaluation seismic loads, vulnerabilities were found for exterior and interior masonry walls. Most structures were found to be adequate for the evaluation earthquake. The vulnerability of masonry walls and missile penetration from tornado winds were also established.

MECHANICAL AND ELECTRICAL SYSTEMS

Field walkdown evaluations utilizing earthquake experience data methodologies have been performed for most safety-related and key support systems. These include auxiliary diesel generators; heating, ventilating, and air conditioning; outdoor and indoor transformers; motor control centers; switchgear; batteries; air compressor systems; tanks; and piping. Recommended modifications which are in progress include upgrading of anchorages to critical equipment to ensure post-earthquake functionality. Other evaluations are ongoing.

EXTERNAL EVENTS SCOPING STUDY AND SEISMIC PRA

EQE is currently supporting Pickard, Lowe, and Garrick in an external events scoping study and seismic and tornado PRA at HFIR. The scoping study is considering all potential external events such as seismic, internal fire, flooding, aircraft impact, extreme wind and tornado, transportation accidents, and pipeline accidents. The objective of the scoping study is to define credible external events and define their hazard frequencies.

In the external events hazard analysis of the PRA, estimates of the frequency of various initiating events occurring at the HFIR site are made. In the fragility evaluation, the conditional probabilities of structural or equipment failure for given levels of ground acceleration or wind velocity are estimated. The systems and accident sequence analysis produces modeling of the various combinations of structural and equipment failures that could initiate and propagate an externally initiated core damage accident sequence. The results of these analyses will be integrated to obtain the frequencies of core damage and to identify seismic vulnerabilities in the facility to aid in decisions on safety upgrading.

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ORNL - 3572. June 1968. "The High Flux Isotope Reactor, a Functional Description." Rev. 2. Vol. 2.

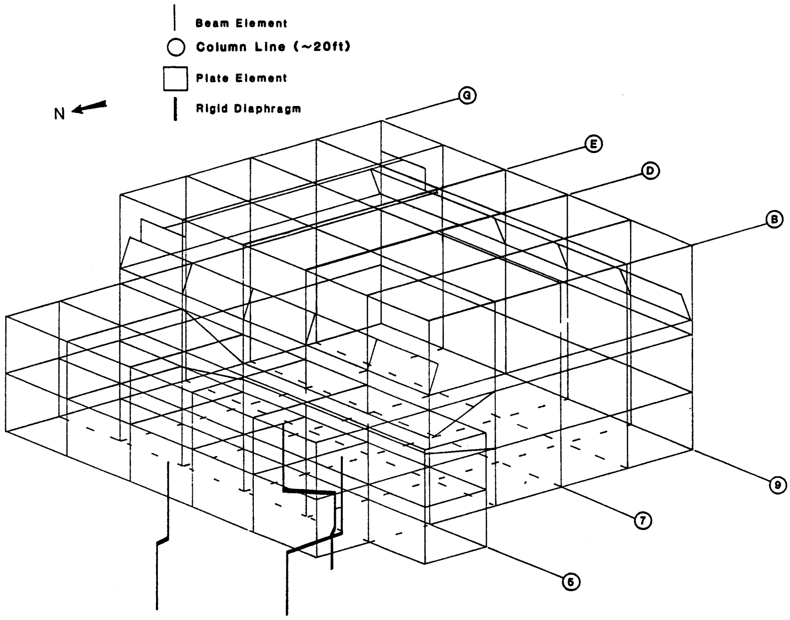

Figure 1: HFIR Building Model Cracked Concrete Analysis

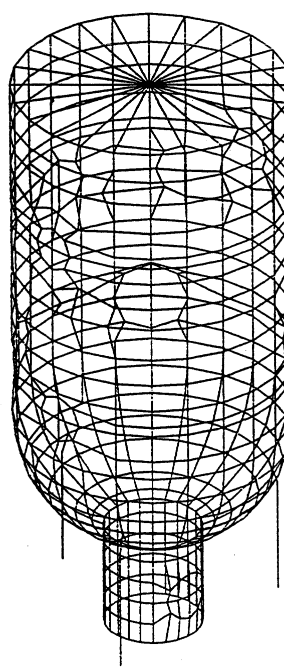

Figure 2: HFIR Reactor Vessel Model

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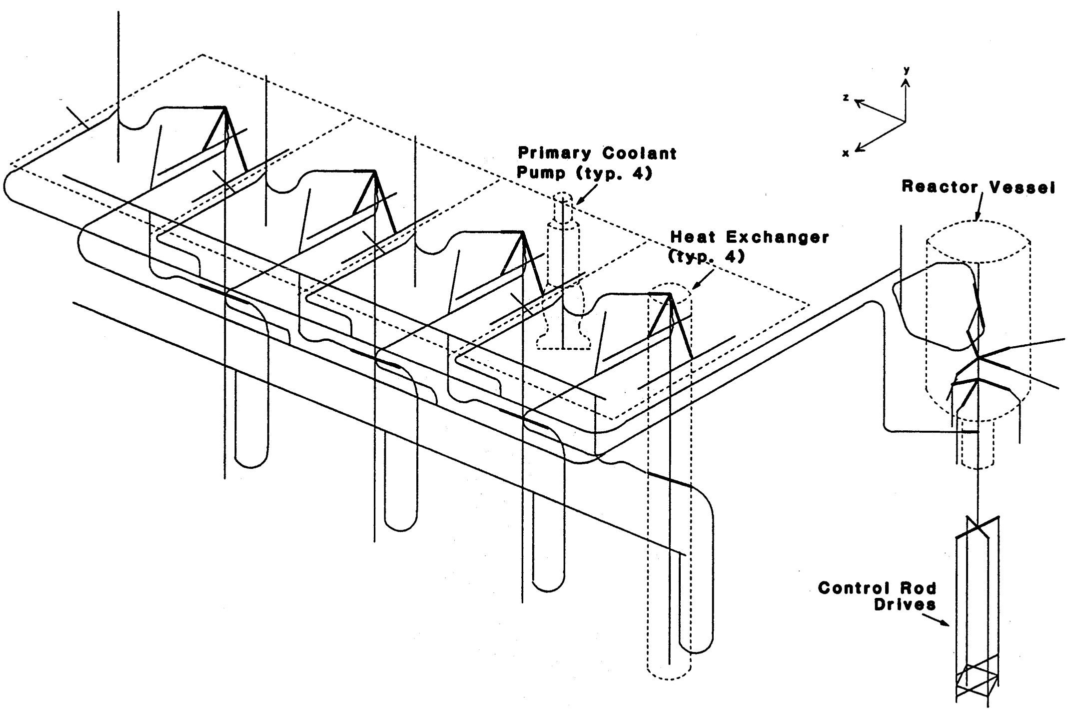

Figure 3: HFIR Reactor and Primary System Model "As Built" Analysis

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