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SEISMIC, HIGH WIND, TORNADO, AND PROBABILISTIC RISK ASSESSMENTS OF THE HIGH FLUX ISOTOPE REACTOR

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ABSTRACT

Natural phenomena analyses were performed on the High Flux Isotope Reactor (HFIR). Deterministic and probabilistic evaluations were made to determine the risks resulting from earthquakes, high winds, and tornadoes. Analytic methods in conjunction with field evaluations and an earthquake experience data base evaluation methods were used to provide more realistic results in a shorter amount of time. Plant modifications completed in preparation for HFIR restart and potential future enhancements are discussed.

INTRODUCTION

The High Flux Isotope Reactor is a high power density research reactor licensed to operate at 85 MWt. It was built in 1965 as a facility to produce transuranic elements.

In 1986, the reactor was shut down in order to evaluate the effects of neutron irradiation on the integrity of the reactor vessel. During this shutdown, it was also considered prudent to evaluate the HFIR design against current codes and practices for modern reactors. To support this evaluation, EQE Engineering was asked to perform deterministic seismic, high wind, and tornado analyses, as well as develop fragility data for a probabilistic risk assessment (PRA).

The assessment was divided into two phases. Phase I consisted of seismic analyses performed on systems required for safe shutdown of the reactor, e.g., reactor scram, decay heat removal, and primary coolant system. Phase II consisted of seismic assessment of the accident mitigation systems, high wind and tornado analyses, and development of fragilities for key components and systems for the PRA.

Based upon industry precedent for older, commercial nuclear plants, the Phase I analyses were planned for completion before reactor restart and the Phase II issues after restart. The Phase I seismic analyses were used as a basis for making plant modifications before restart. The Phase II analyses will be used in conjunction with a PRA to determine the extent of further upgrades to HFIR during its remaining life.

Since HFIR was built over 30 years ago, design criteria for earthquakes and other natural phenomena hazards were considerably less stringent than today. In order to restart HFIR expeditiously, practical and cost effective methods for upgrading the plant were required. A strictly theoretical approach would have been costly and could have been overly conservative, resulting in unnecessary and expensive plant modifications. Therefore, an assessment which included analysis, earthquake experience data base methods, and probabilistic risk assessment methods was planned

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in order to achieve a more realistic determination of the extent of hardware modifications required.

PLANT DESCRIPTION

The HFIR is located at the Oak Ridge National Laboratory in Oak Ridge, Tennessee. It is a pressurized, light water moderated and cooled reactor operating at 85 MWt. The core consists of highly enriched uranium oxide plates clad in aluminum. There are four primary and secondary cooling loops with a water-to-air cooling tower as the heat sink. The pressure vessel is 8 feet in diameter and sits in a reactor pool 17 feet below the surface of the water (Figure 1).

The local geology and site foundation are on a stiff clay shale with an average 20-foot overburden of organic top soil. The seismicity of the site has been studied extensively and the earthquake selected for the deterministic evaluation was a Newark-Hall spectral shape anchored to a 0.15g horizontal peak ground acceleration. High wind and tornado criteria were specified as 150 mph.

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 (Figure 2). 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 vertical input directions, assuming that a combination of dead and seismic loads would affect the shear walls, roof beams, roof slab, and columns. 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. High wind hazard frequency characterization of the HFIR site was 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 3). 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 4). As with the Reactor Building, analyses of the models, including representations of piping and supports, reactor vessel and supports, control rods and support frame, neutron beam tubes, and heat exchanger cell components were performed on the Cray. 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 a 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 to evaluate most active components such as valves (Figure 5).

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 most instances, modifications were recommended and upgrades designed by EQE.

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 consisting of 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 evaluation loads, collapse of the stack is probable 120 feet above the base. Such a collapse would not reach the Reactor Building.

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

The HFIR facility also houses accident mitigation and 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 were performed for most accident mitigation and key support systems. These included auxiliary diesel generators; heating, ventilating, and air conditioning; outdoor and indoor transformers; motor control centers; switchgear; batteries; air compressor systems; tanks; and piping.

FRAGILITIES AND PRA

The objectives of probabilistic risk studies are to estimate the frequencies of occurrence of earthquake or high wind induced accidents, and to identify important risk contributors in the facility design. The elements of risk analysis include 1) hazard analysis of the site, 2) response of plant systems and components, 3) development of component fragilities, and 4) plant systems and event response sequence development.

Plant systems analyses and event response sequences were developed by Pickard Lowe & Garrick. The site hazard characterizations for high wind and tornado were developed by EQE. Response of plant systems, components, and structures described above formed the basis for much of the component fragilities along with additional component and structure-specific analyses.

The objective of fragility evaluation is to estimate the peak ground acceleration or peak wind velocity for which response of a given component or structure exceeds the component capacity resulting in failure. Estimations of peak response parameter are described as a family of curves with a probability value assigned to each curve to reflect the uncertainty and randomness in the fragility estimation.

Fourteen structural failure modes and over 35 mechanical components were evaluated. Evaluations were based on analyses previously described, plant walkdowns, application of earthquake experience data, and component or structure-specific analyses. Components and structures found to have low capacities included the electrical building, reactor pool system tanks, and filters and internal and external masonry walls.

Seismically initiated events were found to be more frequent than high wind or tornado. The dominant seismic sequence was found to involve failure of the electrical building which houses the emergency diesel electric generators and results in the loss of all on-site AC power. Reactor integrity and pool heat sink integrity were maintained in this event sequence. Other sequences involved seismically-induced loss of pool heat sink without loss of integrity of the reactor system.

Significant high wind and tornado events were found to be much less frequent. The top event involves the loss of the electrical building and all on-site AC power. These events in conjunction with wind damage to the emergency DC power supply to the reactor coolant pumps can result in core damage.

CONCLUSIONS AND RECOMMENDATIONS

As a result of the Phase I seismic assessment, 16 plant areas were identified that represented potential seismic hazards to the integrity of the decay heat removal and primary coolant systems. Design changes and subsequent hardware modifications in these areas were completed in 1988. They consisted of 1) strengthening of internal block walls, 2) installation of snubbers and struts on the primary coolant system piping, and 3) restraining coolant lines, let-down valves, radiation monitors, battery chargers, and control rod drive supports. With these upgrades, the HFIR systems required for safe shutdown of the reactor have adequate capacity to survive the 0.15g evaluation earthquake.

Other Phase I results concluded that 1) the HFIR reactor building is adequately designed to preclude collapse on the primary system at 0.15g, and 2) the exhaust stack will not collapse onto the HFIR building during a 0.15g seismic event or 150 mph wind speed tornado event.

Phase II assessments provided the following conclusions:

1. Ancillary sections of the reactor building, such as the control building and water wing, have adequate capacity to preclude collapse during a 0.15g earthquake. However, structural and nonstructural damage may be anticipated.

2. The electrical building, Special Building Hot Exhaust System (SBHE), reactor system tanks, and electrical switchgear are all vulnerable to a 0.15g earthquake. None of these components affect safe shutdown of the reactor, however.

3. Some of the reactor building components, the control building, and water wing are vulnerable to failure during a 150 mph tornado event.

4. A number of interior block walls have insufficient capacity against tornado induced atmospheric pressure change. Where these block walls affect decay heat removal, design modifications have been initiated to strengthen the walls.

5. The electrical building and SBHE are vulnerable to tornado wind pressures.

6. Many parts of the reactor building are susceptible to damage from missiles during a tornado. The damage is not expected to result in core damage based upon preliminary PRA results.

The Phase II results, including the fragilities, have been integrated into the HFIR PRA. Completion of the PRA will determine what, if any, further modifications are desirable to reduce plant risks.

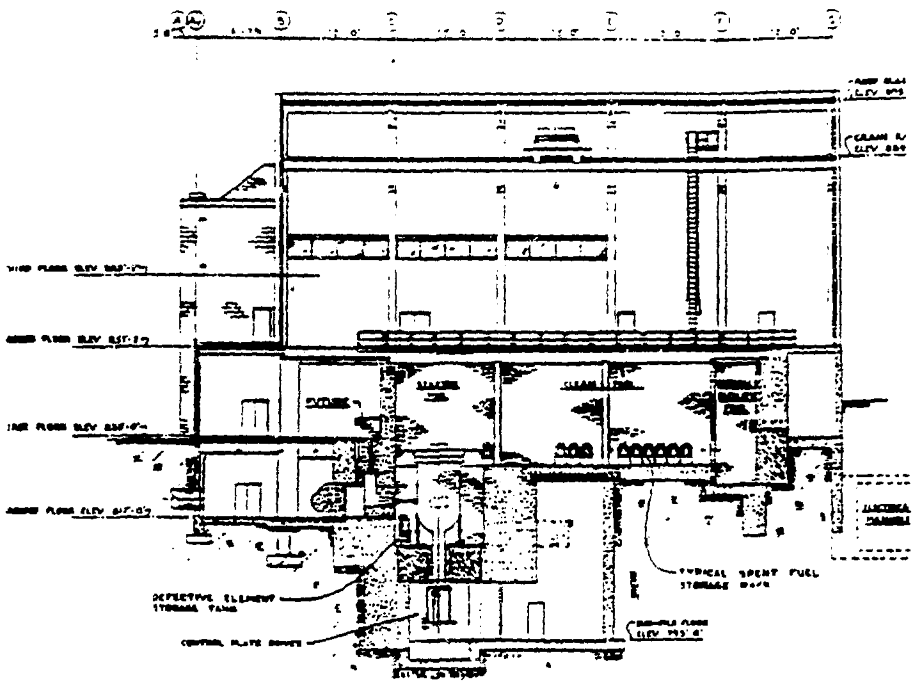

Figure 1: HFIR Reactor Building East-West Section

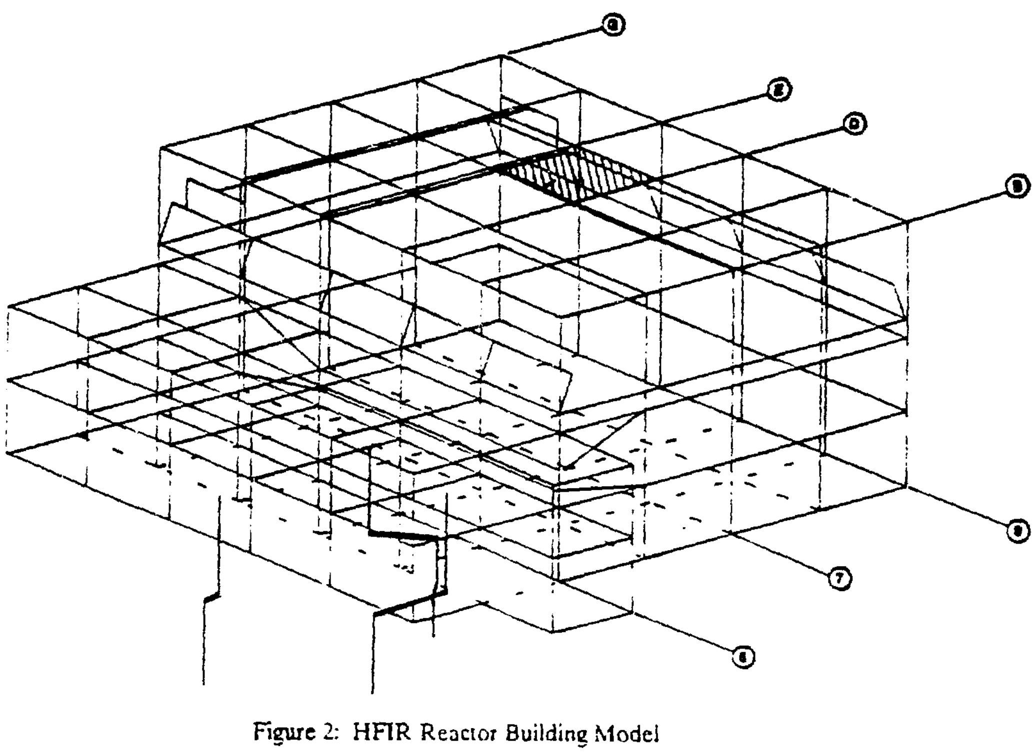

Figure 2: HFIR Reactor Building Model

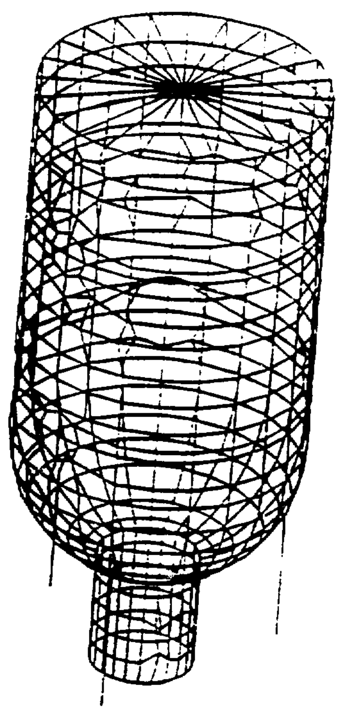

Figure 3: HFIR Reactor Vessel Model

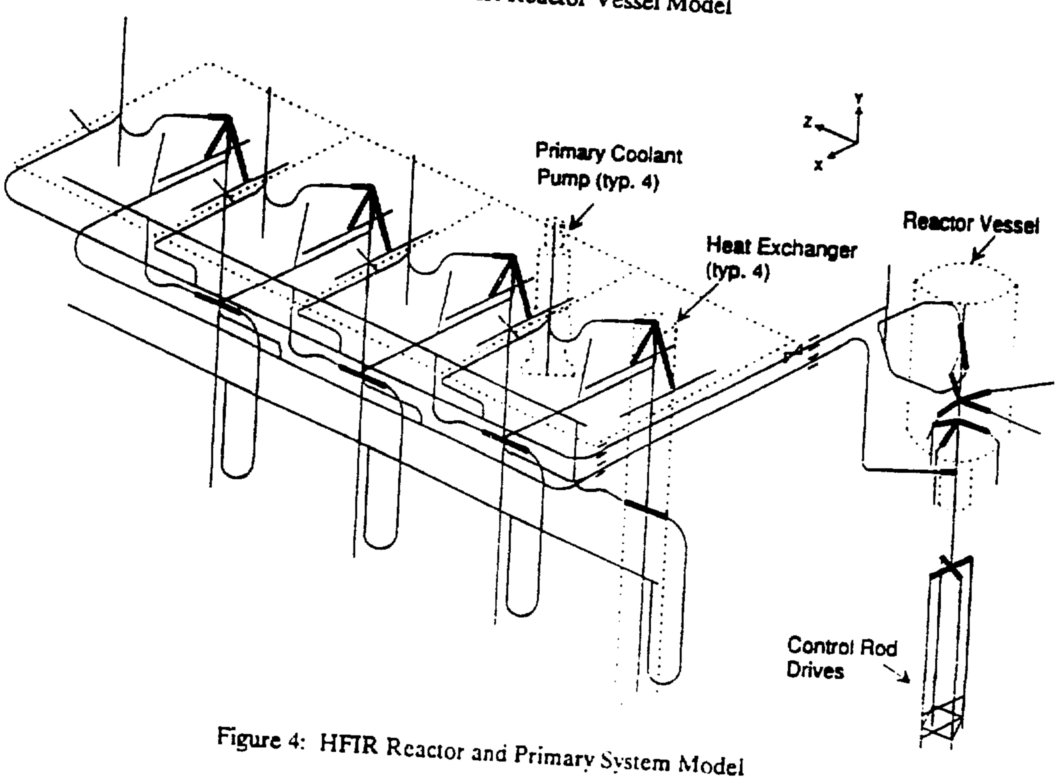

Figure 4: HFIR Reactor and Primary System Model

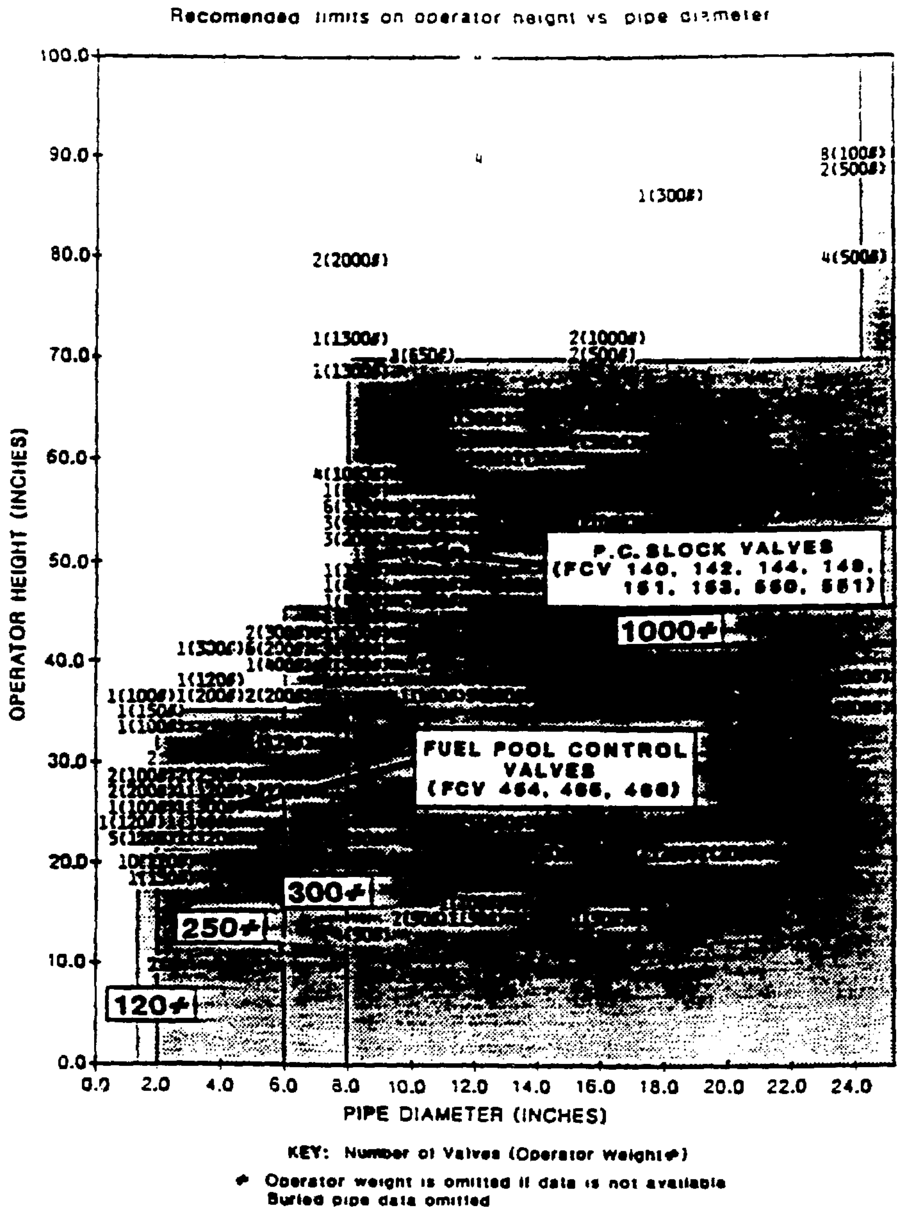

Figure 5: Histogram Representing the Experience Data Base for Motor-operated Valves, with Recommended Restrictions Superimposed