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TMI-2 Vessel Investigation Project Integration Report

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EXECUTIVE SUMMARY

Introduction

On March 28, 1979, a severe accident occurred in the Three Mile Island Unit 2 (TMI-2) pressurized water reactor, which resulted in a partial melting of the core, significant cladding oxidation, and a significant release of fission products from the fuel. Later investigations concluded that at least 45% of the core had melted and approximately 19,000 kg of molten core material relocated and came to rest on the lower head of the reactor vessel.

In order to develop a comprehensive understanding of the accident, several research programs were established. The initial program was jointly sponsored by the General Public Utilities Nuclear (GPUN) Corporation, the Electric Power Research Institute (EPRI), the U.S. Nuclear Regulatory Commission (NRC), and the U.S. Department of Energy (DOE). Collectively, this group was known as GEND. Under the GEND program, GPUN was responsible for ongoing plant cleanup operations, while the DOE was responsible for providing transportation and interim storage of the core until permanent disposition was decided. The DOE also supported an extensive research program, the TMI-2 Accident Evaluation Program, whose objective was to develop a consistent understanding of the accident and to ensure that these results are available for resolution of severe accident issues. An additional research program was formed under the auspices of the Committee on the Safety of Nuclear Installations of the Organization for Economic Cooperation and Development (OECD). Under this program, a number of OECD countries and the Commission of the European Communities' Joint Research Centre participated in the Accident Evaluation Program by performing detailed examinations of samples of fuel debris.

Formation of the Vessel Investigation Project

When the GEND research program was originally established, it was not expected that a significant amount of molten material had relocated to the lower head. As a result, further study of the implications associated with the relocation of fuel and a potentially damaged lower head was not included in the GEND program work scope. Once it was realized that molten fuel had relocated to the lower head, the NRC proposed that the important safety questions raised by a potentially damaged lower head be further investigated through a joint international cooperative program under the sponsorship of the Nuclear Energy Agency (NEA) of the OECD. During initial discussions concerning the formation of the Vessel Investigation Project (VIP), it became clear that countries which operated nuclear power reactors needed to further increase their overall understanding of the TMI-2 accident. This would best be accomplished through joint international participation in an additional TMI-2 research program. As a result, the OECD "Project To Investigate The Three Mile Island 2 Reactor Pressure Vessel," commonly called the TMI-2 VIP, was established. The signatories to the formal VIP agreement are Belgium, Finland, France, Germany, Italy, Japan, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

Control of the VIP was vested in a Management Board, which consisted of one member designated by each signatory. A Program Review Group was formed to act as the technical

§ 50.44 Combustible gas control for nuclear power reactors.

(a) *Definitions.*

(1) *Inerted atmosphere* means a containment atmosphere with less than 4 percent oxygen by volume.

(2) *Mixed atmosphere* means that the concentration of combustible gases in any part of the containment is below a level that supports combustion or detonation that could cause loss of containment integrity.

(b) *Requirements for currently-licensed reactors.* Each boiling or pressurized water nuclear power reactor with an operating license on October 16, 2003, except for those facilities for which the certifications required under § 50.82(a)(1) have been submitted, must comply with the following requirements, as applicable:

(1) *Mixed atmosphere.* All containments must have a capability for ensuring a mixed atmosphere.

(2) *Combustible gas control.* (i) All boiling water reactors with Mark I or Mark II type containments must have an inerted atmosphere.

(ii) All boiling water reactors with Mark III type containments and all pressurized water reactors with ice condenser containments must have the capability for controlling combustible gas generated from a metal-water reaction involving 75 percent of the fuel cladding surrounding the active fuel region (excluding the cladding surrounding the plenum volume) so that there is no loss of containment structural integrity.

(3) *Equipment Survivability.* All boiling water reactors with Mark III containments and all pressurized water reactors with ice condenser containments that do not rely upon an inerted atmosphere inside containment to control combustible gases must be able to establish and maintain safe shutdown and containment structural integrity with systems and components capable of performing their functions during and after exposure to the environmental conditions created by the burning of hydrogen. Environmental conditions caused by local detonations of hydrogen must also be included, unless such detonations can be shown unlikely to occur. The amount of hydrogen to be considered must be equivalent to that generated from a metal-water reaction involving 75 percent of the fuel cladding surrounding the active fuel region (excluding the cladding surrounding the plenum volume).

(4) *Monitoring.* (i) Equipment must be provided for monitoring oxygen in containments that use an inerted atmosphere for combustible gas control. Equipment for monitoring oxygen must

be functional, reliable, and capable of continuously measuring the concentration of oxygen in the containment atmosphere following a significant beyond design-basis accident for combustible gas control and accident management, including emergency planning.

(ii) Equipment must be provided for monitoring hydrogen in the containment. Equipment for monitoring hydrogen must be functional, reliable, and capable of continuously measuring the concentration of hydrogen in the containment atmosphere following a significant beyond design-basis accident for accident management, including emergency planning.

(5) *Analyses.* Each holder of an operating license for a boiling water reactor with a Mark III type of containment or for a pressurized water reactor with an ice condenser type of containment, shall perform an analysis that:

(i) Provides an evaluation of the consequences of large amounts of hydrogen generated after the start of an accident (hydrogen resulting from the metal-water reaction of up to and including 75 percent of the fuel cladding surrounding the active fuel region, excluding the cladding surrounding the plenum volume) and include consideration of hydrogen control measures as appropriate;

(ii) Includes the period of recovery from the degraded condition;

(iii) Uses accident scenarios that are accepted by the NRC staff. These scenarios must be accompanied by sufficient supporting justification to show that they describe the behavior of the reactor system during and following an accident resulting in a degraded core.

(iv) Supports the design of the hydrogen control system selected to meet the requirements of this section; and,

(v) Demonstrates, for those reactors that do not rely upon an inerted atmosphere to comply with paragraph (b)(2)(ii) of this section, that:

(A) Containment structural integrity is maintained. Containment structural integrity must be demonstrated by use of an analytical technique that is accepted by the NRC staff in accordance with § 50.90. This demonstration must include sufficient supporting justification to show that the technique describes the containment response to the structural loads involved. This method could include the use of actual material properties with suitable margins to account for uncertainties in modeling, in material properties, in construction tolerances, and so on; and

(B) Systems and components necessary to establish and maintain safe shutdown and to maintain containment integrity will be capable of performing their functions during and after exposure to the environmental conditions created by the burning of hydrogen, including local detonations, unless such detonations can be shown unlikely to occur.

(c) *Requirements for future water-cooled reactor applicants and licensees.*[2] The requirements in this paragraph apply to all water-cooled reactor construction permits or operating licenses under this part, and to all water-cooled reactor design approvals, design certifications, combined licenses or manufacturing licenses under part 52 of this chapter, any of which are issued after October 16, 2003.

(1) *Mixed atmosphere.* All containments must have a capability for ensuring a mixed atmosphere during design-basis and significant beyond design-basis accidents.

(2) *Combustible gas control.* All containments must have an inerted atmosphere, or must limit hydrogen concentrations in containment during and following an accident that releases an equivalent amount of hydrogen as would be generated from a 100 percent fuel clad-coolant reaction, uniformly distributed, to less than 10 percent (by volume) and maintain containment structural integrity and appropriate accident mitigating features.

(3) *Equipment Survivability.* Containments that do not rely upon an inerted atmosphere to control combustible gases must be able to establish and maintain safe shutdown and containment structural integrity with systems and components capable of performing their functions during and after exposure to the environmental conditions created by the burning of hydrogen. Environmental conditions caused by local detonations of hydrogen must also be included, unless such detonations can be shown unlikely to occur. The amount of hydrogen to be considered must be equivalent to that generated from a fuel clad-coolant reaction involving 100 percent of the fuel cladding surrounding the active fuel region.

(4) *Monitoring.* (i) Equipment must be provided for monitoring oxygen in containments that use an inerted atmosphere for combustible gas control. Equipment for monitoring oxygen must be functional, reliable, and capable of continuously measuring the concentration of oxygen in the containment atmosphere following a significant beyond design-basis accident for combustible gas control and accident management, including emergency planning.

(ii) Equipment must be provided for monitoring hydrogen in the containment. Equipment for monitoring hydrogen must be functional, reliable, and capable of continuously measuring the concentration of hydrogen in the containment atmosphere following a significant beyond design-basis accident for accident management, including emergency planning.

(5) *Structural analysis.* An applicant must perform an analysis that demonstrates containment structural integrity. This demonstration must use an analytical technique that is accepted by the NRC and include sufficient supporting justification to show that the technique describes the containment response to the structural loads involved. The analysis must address an accident that releases hydrogen generated from 100 percent fuel clad-coolant reaction accompanied by hydrogen burning. Systems necessary to ensure containment integrity must also be demonstrated to perform their function under these conditions.

(d) *Requirements for future non water-cooled reactor applicants and licensees and certain water-cooled reactor applicants and licensees.* The requirements in this paragraph apply to all construction permits and operating licenses under this part, and to all design approvals, design certifications, combined licenses, or manufacturing licenses under part 52 of this chapter, for non water-cooled reactors and water-cooled reactors that do not fall within the description in paragraph (c), footnote 1 of this section, any of which are issued after October 16, 2003. Applications subject to this paragraph must include:

(1) Information addressing whether accidents involving combustible gases are technically relevant for their design, and

(2) If accidents involving combustible gases are found to be technically relevant, information (including a design-specific probabilistic risk assessment) demonstrating that the safety impacts of combustible gases during design-basis and significant beyond design-basis accidents have been addressed to ensure adequate protection of public health and safety and common defense and security.

[43 FR 50163, Oct. 27, 1978, as amended at 46 FR 58486, Dec. 2, 1981; 50 FR 3504, Jan. 25, 1985; 50 FR 5567, Feb. 11, 1985; 51 FR 40308, Nov. 6, 1986; 53 FR 43420, Oct. 27, 1988; 57 FR 39358, Aug. 31, 1992, 61 FR 39299, July 29, 1996; 64 FR 48951, Sept. 9, 1999; 68 FR 54141, Sep. 16, 2003]

[2] The requirements of this paragraph apply only to water-cooled reactor designs with characteristics (e.g., type and quantity of cladding materials) such that the potential for production of combustible gases is comparable to light water reactor designs licensed as of October 16, 2003.