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SAFETY CONSIDERATIONS IN THE DESIGN
OF THE FUSION ENGINEERING DEVICE

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ABSTRACT

Safety considerations play a significant role in the design of a near-term Fusion Engineering Device (FED). For the safety of the general public and the plant workers, the radiation environment caused by the reacting plasma and the potential release of tritium fuel are the dominant considerations.

The U.S. Department of Energy (DOE) regulations and guidelines for radiation protection have been reviewed and are being applied to the device design. Direct radiation protection is provided by the device shield and the reactor building walls. Radiation from the activated device components and the tritium fuel is to be controlled with shielding, contamination control, and ventilation. The potential release of tritium from the plant has influenced the selection of reactor building and plant designs and specifications.

The safety of the plant workers is affected primarily by the radiation from the activated device components and from plasma chamber debris. The highly activated device components make it necessary to design many of the maintenance activities in the reactor building for totally remote operation. The hot cell facility has evolved as a totally remote maintenance facility due to the high radiation levels of the device components.

Safety considerations are having substantial impacts on the design of FED. Several examples of safety-related design impacts

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are discussed in the paper. Feasible solutions have been identified for all outstanding safety-related items, and additional optimization of these solutions is expected as detailed designs progress.

INTRODUCTION

Safety considerations play a significant role in the design of the Fusion Engineering Device (FED). All aspects of safety must be considered, even in the earliest design activities. The dominant consideration for the safety of the general public and plant workers is the radiation environment created by the reacting plasma and tritium fuel.

The FED, as described^{1,2} is a near-term tokamak device that is designed to burn a tritium-deuterium fuel to produce about 200 MW of fusion power, with about 0.5-MW/m² neutron wall loading and about 100-s burn time. Since the FED objectives involve the use of tritium fuel and production of substantial quantities of activated material, most of the unique safety hazards are a consequence of the radioactivity. Many of the safety considerations described for FED may be applicable to other near-term fusion devices as well.

SAFETY STANDARDS AND CRITERIA

Since FED was proposed as a DOE project, safety standards and criteria are based upon DOE orders and procedures. For DOE projects, DOE Order 5480, Chapter V³ and Chapter XI⁴ provide the basis for establishing safety criteria and give several applicable guidelines. The report, "Nonreactor Nuclear Facilities: Standards and Criteria Guide,"⁵ has also been very helpful in establishing guidelines. The DOE policy is to limit radiation exposure to individuals and population groups to a level "as low as

reasonably achievable" (ALARA). Most of the task of interpreting the ALARA policy falls under the DOE safety and analysis review system, as described in DOE Order 5481.1.⁶ and DOE/ET-0044.⁷ However, some guidelines have been established so that early design activities may proceed before any safety review is undertaken because the issue of limiting radioactive exposure to the general public and plant workers has a major impact on the basic configuration of the reactor and facilities. Suggested radiation exposure guidelines for use with FED have been developed to guide design activities. The two most influential dose guidelines have been 1.0 REM/yr for plant workers and a maximum of 25 REM dose to offsite personnel during the most severe design basis accident. Other interim exposure guidelines have also been adopted for FED.

The discussion of confinement systems⁵ has been reviewed and adapted to the FED situation. The use of primary, secondary, and tertiary confinement systems should prevent or mitigate the effects of an uncontrolled release of radioactive material so as to keep on-site and off-site doses and effluent concentrations within recommended guidelines.

Confinement capabilities are based on the ability of ventilation systems to maintain a controlled, continuous airflow pattern from the environment into the confinement building, from noncontaminated building areas to potentially contaminated areas, and then to normally contaminated areas. The level of radioactivity in the confinement exhaust must be continuously monitored and alarmed to detect high activity in the exhaust stream.

The safety importance of various parts of the plant⁵ implies the adoption of special quality and reliability standards to establish a high level of assurance that safety-related functions will be performed as designed. These special attributes include the ability to withstand severe natural phenomena. The implications of safety class designation need to be worked out specifically for FED as the design progresses.

DESIGN IMPACTS OF PUBLIC SAFETY

Direct Radiation

Direct radiation to the general public from FED during either operation or shutdown will be controlled with both shielding and distance. The main biological shielding is the building walls and roofs of those buildings that contain significant radiation sources. In addition, an exclusion area will be defined around the plant to restrict access of the general public, thereby limiting the potential of exposure to radiation.

Release of Radioactive Material

Since the impact of released tritium on the general public is a basic concern, the potential concentration and dose rate at the exclusion boundary due to accidental tritium release are important parameters for plant design. These tritium concentrations and dose rates depend on a number of variables, many of which are site dependent (e.g., the distance to the site exclusion boundary; potential wind, atmospheric, and topographic conditions; and the building and ventilation system designs). Calculating the dose from tritium release requires information about the plant design and site that is not currently available for FED. However, efforts have been made to bracket the possible consequences by comparisons by EC&G Idaho⁸ of tritium dose calculations from several tritium-containing facilities under accident and normal operating conditions. These comparisons suggest that FED dose rate consequences lie somewhere between 6.5×10^{-6} and 2.0×10^{-4} rem/Ci for postulated accidental ground-level releases of tritium in the oxide form. The possible dose rates from postulated releases and the amount of tritium expected in the plant imply that some confinement systems will be necessary to prevent accidental ground-level release of tritium.

Impact on Building Designs

The safety of the general public has required considerable design attention for building designs to prevent the potential release of tritium from the FED plant. Several examples of these design impacts are included with other safety impacts in Figs. 1 and 2. Activation products caused

Fig 1. Reactor Building Design Features and Criteria Influenced by Safety Consideration

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Figure 2 Hot Cell Facility Design Features and Criteria Influenced by Safety Considerations

by the reacting plasma and its neutrons do not play an important role in public safety considerations because these activation products are easily contained within the plant using current technology.

The reactor building, the hot cell facility, the tritium process building, and the radioactive waste treatment building are part of the confinement systems to control radioactive release. These buildings will have special requirements and criteria to help insure adequate control of radioactive materials and tritium. One design approach expected to be applied is the compartmentalization of radioactive sources. A major example of this approach is the specification of a separate building for tritium processing so that the bulk of tritium processing operations and storage can be physically separated from the operational activities and hazards of the reactor.

In all of these buildings, tritium-containing systems are to be placed within partitioned cells where the ventilation can be controlled and monitored. These cells will help to confine the tritium and prevent its mixing with the entire building volume. A major source of tritium release is expected from the leakage of cooling systems that become contaminated with tritium. The major components of cooling systems, including pumps, valves, and heat exchangers, are to be placed in the cells in the reactor building.

Tritium confinement in the reactor building has had a major influence on the reactor building size and shape, as discussed by Barrett and Thomson.³ The rectangular reactor building that has been selected relies heavily on ventilation system design and partitioning of tritium inventories to control potential tritium releases. Release of cryogenic liquid helium from the magnets represents the largest potential source of reactor building pressurization. The scoping studies² show that the time scale of helium release and building pressurization is long enough to allow ventilation systems to react and assure release through the ventilation stack, which greatly reduces the impact of any radioactive release. For tritium releases that are not accompanied by pressurization mechanisms, the building can be isolated and the tritium levels reduced to acceptable levels before release. Tritium handling equipment within the reactor building is being designed with three levels of confinement to prevent accidental releases of tritium. Since the reactor building is a major part of the confinement, the structural design of the building is expected to be based on criteria for withstanding severe natural phenomena (i.e., earthquakes and tornadoes), as well as device-related actions such as liquid helium release and interior missiles.

Tritium confinement within the tritium processing building is expected to be provided using

state-of-the-art tritium control techniques, which include special cells, ventilation systems, glove boxes, and double-walled piping. Research and development work for TSTA is expected to contribute greatly to the design of these facilities.

The source of tritium in the hot cell facility is expected to be the release by maintenance operations of tritium entrapped in the components. Tritium releases from components are expected to be relatively slow at normal building temperatures. However, welding and cutting operations, required for maintenance activities in the hot cell facility, may greatly enhance the release of tritium to the hot cell atmosphere. An inert hot cell atmosphere (e.g., argon gas) is being considered to aid in the recovery of tritium, in addition to other possible advantages.

While only low levels of tritium are expected in processed coolants within the radioactive waste treatment facility, they are sufficient to require continuous monitoring and control of the building atmosphere.

Effect on Reactor Design

The design of the FED reactor is also being influenced by the need for tritium confinement. Seals and seal welds in several areas of reactor design are being evaluated for their tritium leak rates. The decision to use turbomolecular vacuum pumps was influenced by the need to reduce the tritium inventories from those expected in cryogenic vacuum pumps. Special attention has been given to coolant system design to segregate those coolants with the highest tritium concentration to allow better control of the tritium which permeates through the first wall into the coolant channels. Magnet cooling systems are being designed to help reduce potential cryogenic releases during magnet accidents.

SAFETY OF THE PLANT WORKERS

Most of the safety considerations for the plant workers fall into the category of normal industrial hazards, such as high-voltage electricity, handling heavy weights, handling toxic chemicals, and handling cryogenic fluids. Most of these hazards can be dealt with using normal industrial safety criteria and techniques. The radioactivity hazards produced within the reactor can also be dealt with using established procedures and techniques. However, the consideration of the radiation

hazards to the work force is having a major impact on the FED design.

Tritium is also a safety consideration for plant workers and dictates some of the confinement system designs. However, the most important concern is direct radiation from activated components and materials. A number of the components that require maintenance operation are in direct contact with the plasma and are expected to become highly radioactive during reactor operation. Thus, the maintenance operations on the machine lead to potential exposure of the plant workers and radioactive contamination of the plant facilities. Operation and maintenance of this facility will require substantial health physics support, as well as supplemental facilities such as change rooms, showers, and radioactive laundry areas.

Direct Radiation Protection

The current maintenance philosophy for FED requires that levels of radiation within the reactor building should permit hands-on maintenance of components and equipment outside the reactor. The current design guideline is a 2.5-rem/hr dose rate 24 h after shutdown. However, opening the plasma chamber and removing the components in contact with the plasma must be done remotely to protect workers from excessive radiation. Hands-on maintenance operations have been an important criterion for reactor shielding design. Remote maintenance of the reactor components is the major factor in sizing the reactor building and provides the major justification for the hot cell facility. Reactor building walls serve as the primary biological shielding system for the reactor and prevent high levels of radiation outside the reactor building during device operations and maintenance. Approximately 2 m of ordinary concrete is currently required for both of these functions. Since the hot cell walls must also protect the maintenance staff from the direct radiation of the disassembled components, as much as 2 m of concrete is also required for the hot cell walls.

The potential activation of the reactor building walls and structures by neutrons from the reactor during operation may lead to greater dose rates than the current FED guideline for contact maintenance. The addition of boron to the first 0.3 m of concrete has been suggested to substantially reduce the concrete activation. Another option is to carefully

specify the concrete aggregate to reduce those elements that contribute most to the activation.

Contamination Control

Contamination control within the reactor building and hot cell facility is required to protect the working environment of the plant. Transport of components is a major factor in contamination control. A major part of the hot cell facility is required for contamination control. Ventilation system airflows must also be designed to help control the flow of contamination within the reactor building and the hot cell facility.

The major sources of contamination in the reactor building are the radioactive dust and debris released from the plasma vacuum chamber during maintenance operations. The activated steel dust with its cobalt isotopes is the most potent of these radioactive materials. Maintenance procedures specify vacuum cleaning of the plasma chamber before the torus sector is removed, and equipment is being designed to enclose torus shield sectors during removal and transport within the reactor building to minimize the spread of this contamination. Floors and structural members near the device are expected to be lined with steel to make decontamination activities possible. Ventilation systems will be expected to remove radioactive dust from the building atmosphere.

The most important sources of contamination in the hot cell facility will be the cutting, welding, and grinding operations on radioactive components. The expected contamination has led to a specification of a wide variety of design characteristics for the hot cell facility.² Most all of the hot cell facility design features are influenced by the need to control contamination, including ventilation systems, component transportation systems, remote maintenance techniques, repair of remote maintenance equipment, maintenance procedures, and hot cell atmosphere.

Conclusions

Safety considerations for FED are having a substantial impact on the device and facility design. These impacts are expected to be present for any major fusion device design activity. Feasible solutions to all outstanding safety-related problems have been identified for current design descriptions.

Additional optimization of these solutions is expected as detailed designs progress.

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