

Transient response and radiation dose estimates for breaches to a spent fuel processing facility



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HIGHLIGHTS

- We model doses received from a nuclear fuel facility from boundary leaks due to an earthquake.
- The supplemental exhaust system (SES) starts after breach causing air to be sucked into the cell.
- Exposed metal fuel burns increasing pressure and release of radioactive contamination.
- Facility releases are small and much less than the limits showing costly refits are unnecessary.
- The method presented can be used in other nuclear fuel processing facilities.

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ABSTRACT

This paper describes the analysis of the design basis accident for Idaho National Laboratory Fuel Conditioning Facility (FCF). The facility is used to process spent metallic nuclear fuel. This analysis involves a model of the transient behavior of the FCF inert atmosphere hot cell following an earthquake initiated breach of pipes passing through the cell boundary. Such breaches allow the introduction of air and subsequent burning of pyrophoric metals. The model predicts the pressure, temperature, volumetric releases, cell heat transfer, metal fuel combustion, heat generation rates, radiological releases and other quantities. The results show that releases from the cell are minimal and satisfactory for safety. This analysis method should be useful in other facilities that have potential for damage from an earthquake and could eliminate the need to back fit facilities with earthquake proof boundaries or lessen the cost of new facilities.

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1. Background

The Idaho National Laboratory (INL) Fuel Conditioning Facility (FCF), shown in Fig. 1 with the Experimental Breeder Reactor II (EBR-II) in the background, is engaged in electrometallurgical treatment, also known as pyroprocessing, of sodium-bonded spent nuclear fuel. Owing to the highly radioactive nature of spent fuel as well as the pyrophoric nature of some of the materials involved, the entire process is conducted within an inert argon gas hot cell.

Safety analyses of possible incidents and highly unlikely accidents are required in order to operate such a facility. The design basis accident (DBA) for this facility is an earthquake which causes failure of hot cell penetrations that supply argon gas, provide cell atmosphere cooling and purification, and facilitate remote operations. Failure of hot cell penetrations can allow air to enter process areas normally filled with argon gas. These process areas contain

pyrophoric metal laden with radioactive materials. The introduction of air can precipitate combustion and a resulting release of radioactive material. A supplemental exhaust system was designed and installed to prevent unfiltered atmospheric releases from this accident. This paper predicts the transient behavior of hot cell atmosphere following a seismically induced breach and estimates the potential resulting radiation doses. The analysis procedure should prove useful for predicting the course of accidents in other hot cells.

FCF, originally called the Fuel Cycle Facility, was activated in 1963 with the mission of demonstrating fuel reprocessing and fabrication in a facility closely coupled to EBR-II (Stevenson, 1987). In conjunction with the Argonne National Laboratory Integral Fast Reactor Program, facility modifications were carried out in the late 1980s and early 1990s to allow demonstration of electrometallurgical treatment of spent fuel (Till and Chang, 2012). Treatment operations began in 1996 and continue today.

Fig. 2 shows the FCF hot cell layout. Pyroprocessing spent metallic nuclear fuel requires the use of an inert atmosphere to maintain product purity and because pyrophoric materials, such

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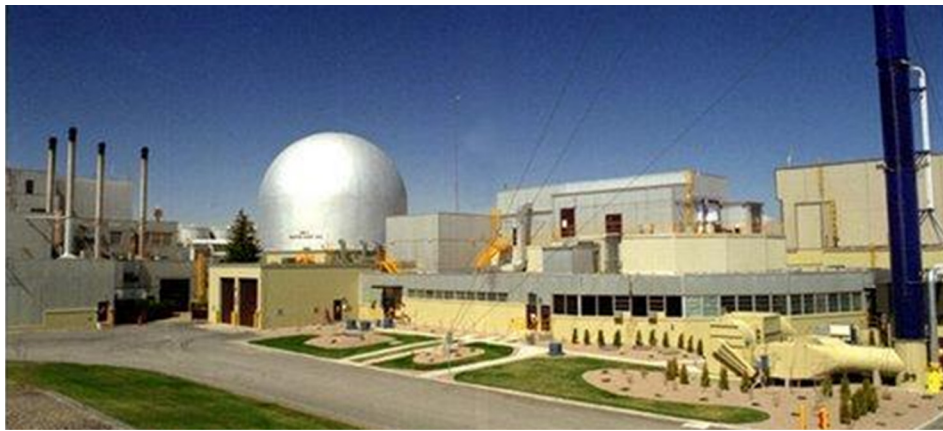


Fig. 1. Fuel Conditioning Facility.

as the cathode deposits, are produced at certain points in the process. The rectangular portion of the hot cell contains an air atmosphere and is used for spent fuel and product storage. The annular portion of the hot cell contains an argon atmosphere and is used for all processing steps. The air cell is a reinforced concrete structure with nominal internal dimensions of $47 \times 15 \times 21$ ft. The cell walls are 5-ft-thick high-density concrete. There are eight windows located in the perimeter wall of the air cell. The argon cell is a hexadecagon-shaped reinforced concrete structure with a central observation room. The annulus of the argon cell has an outer nominal diameter of 62 ft, an inner nominal diameter of 30 ft, and an inside nominal height of 22.5 ft. The cell walls are 5-ft-thick high-density concrete. The argon cell unoccupied volume is 66,000 ft³. The argon cell is completely lined with a seal-welded steel liner 3/8 in. thick on the walls and ceiling and 1/2 in. thick on the floor. There are 15 windows located in the outer wall of the cell and four windows in the central observation room. Items are transferred into and out of the argon cell using either the small transfer lock or the equipment transfer lock. The small transfer lock is embedded in the wall between the air cell and argon cell.

The equipment transfer lock is embedded in the floor between the argon cell and a transfer tunnel which is connected to the air cell.

Fig. 3 shows the general process flow (Pope, 2007). The spent fuel typically consists of stainless steel cladding with a uranium-zirconium alloy fuel slug and sodium metal added between the fuel slug and cladding to enhance heat transfer in the reactor. The process starts with chopping spent fuel elements into element segments. The element segments are placed in a stainless-steel basket. The basket is lowered into an electrorefiner which contains molten salt (LiCl–KCl) along with a steel mandrel.

In the electrolyrefiner, see Fig. 4, active metal fission products, transuranic metals and sodium metal in the spent fuel undergo chemical oxidation and form chlorides. Voltage is applied between the basket, which serves as an anode, and the mandrel, which serves as a cathode, causing metallic uranium in the spent fuel to undergo electro-chemical oxidation thereby forming uranium chloride. Simultaneously at the cathode, uranium chloride undergoes electro-chemical reduction and deposits uranium metal onto the mandrel. Fission products, plutonium and other transuranic metals remain as chlorides in the salt.

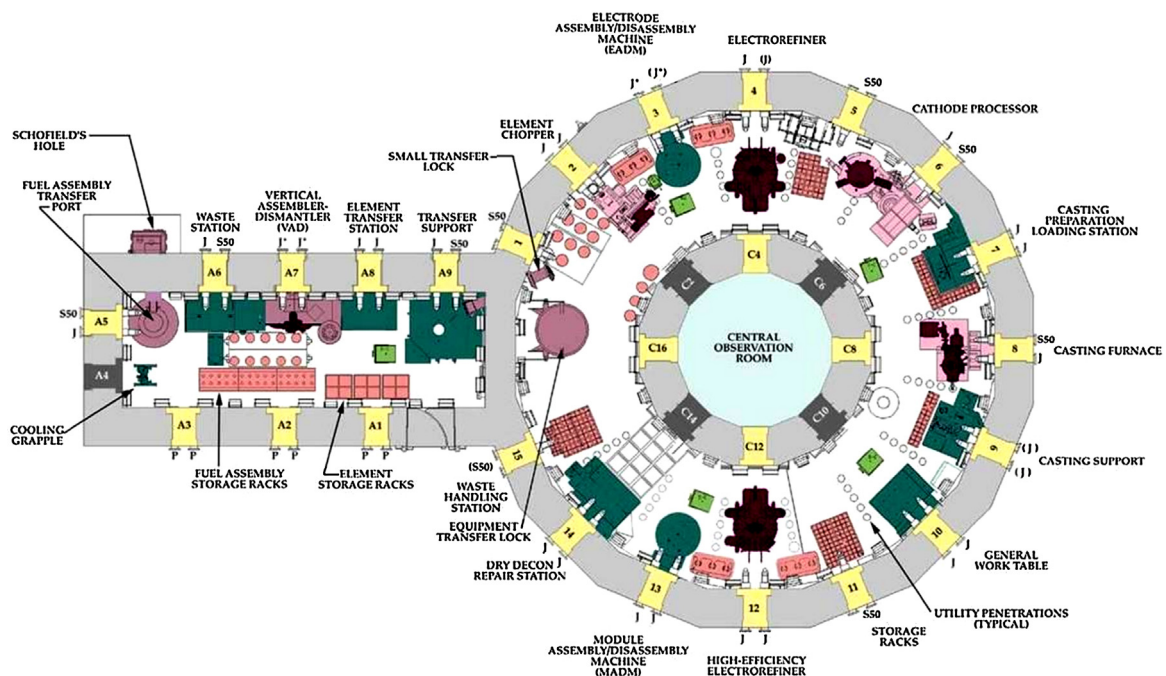


Fig. 2. Facility layout.

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