CONF-930403--76

IFR FUEL CYCLE PROCESS EQUIPMENT DESIGN ENVIRONMENT AND OBJECTIVES

ANL/FC/CP--78692

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ABSTRACT Argonne National Laboratory (ANL) is refurbishing the hot cell facility originally constructed with the EBR-II reactor. When refurbishment is complete, the facility will demonstrate the complete fuel cycle for current generation high burnup metallic fuel elements. These are sodium bonded, stainless steel clad fuel pins of U-Zr or U-Pu-Zr composition typical of the fuel type proposed for a future Integral Fast Reactor (IFR) design. To the extent possible, the process equipment is being built at full commercial scale, and the facility is being modified to incorporate current DOE facility design requirements and modern remote maintenance principles. The current regulatory and safety environment has affected the design of the fuel fabrication equipment, most of which will be described in greater detail in subsequent papers in this session.

INTRODUCTION

The EBR-II fast reactor and associated hot cell facilities were originally designed and constructed in the early 1960's. They were used successfully for several years to demonstrate a closed fuel cycle for EBR-II using an early metallic fuel design and reprocessing scheme. The controlling features of that system with respect to facility and process equipment design were:

a. Low fuel burnup limits, leading to a desire for fast turnaround of highly radioactive fuel

b. Relatively high throughput in relatively simple equipment

c. Limited concern with in-cell contamination levels, equipment repairability, or determination of "commercial" economics

d. Relatively lower regulatory concern with issues such as confinement boundary integrity after design basis accidents.

All of these features have undergone major change in the past 30 years and have led to a significant rethinking on how certain equipment design and facility layout issues should be dealt with. In our particular case, the principal changes having the largest impact are the following:

a. Fuel burnup limits that are 5 to 10 times higher than 30 years ago, leading to less emphasis on throughput capacity and turnaround time

b. A greatly heightened regulatory and safety review concern with post-DBA confinement boundary integrity, passive confinement and cooling systems, and ALARA personnel radiation exposure issues

c. A demonstration-driven need to investigate commercial economics, remote equipment repairability, and waste minimization

d. Use of commercial scale equipment and batch sizes to support a small reactor

The net effect of these changes has been to require an increase in the confinement boundary integrity of all process equipment and facility systems, to markedly decrease the number of confinement boundary penetrations that could be credible paths for air ingress or contamination escape under post-DBA conditions, and to minimize potentially pyrophoric materials exposed to the argon cell atmosphere even under normal operating conditions.

The focus of this paper is how the current regulatory environment and the needs of the demonstration project have influenced the design of the fuel element fabrication equipment and the interfacing handling magazine.

FACILITY DESCRIPTION

The key Fuel Cycle Facility (FCF) features relevant to the confinement boundary and other safety issues influencing the process equipment design are two heavily shielded hot cells and a lightly shielded repair area.

The Air Cell is a 66 m^2 concrete cell with 8 windows, 16 master/slave mechanical manipulators, two 340 kg capacity electromechanical manipulators (EMM), and a 4,500 kg capacity crane. Three m^3/second filtered air flow is provided for cooling and pressure gradient control. Only encapsulated fuel materials are handled in this cell.

The Argon Cell is a 220 m^2 cell with a welded steel liner, 19 windows, 26 master/slave mechanical manipulators, 4 EMM's, and 2 cranes. It has an inert atmosphere with a closed loop cooling and purification system with 220 kW heat removal capability. Unencapsulated fuel materials are only handled in this cell. Both hot cells have remote repair/recovery capability for all active components of the handling systems. These cells and their process equipment are shown in Figure 1.

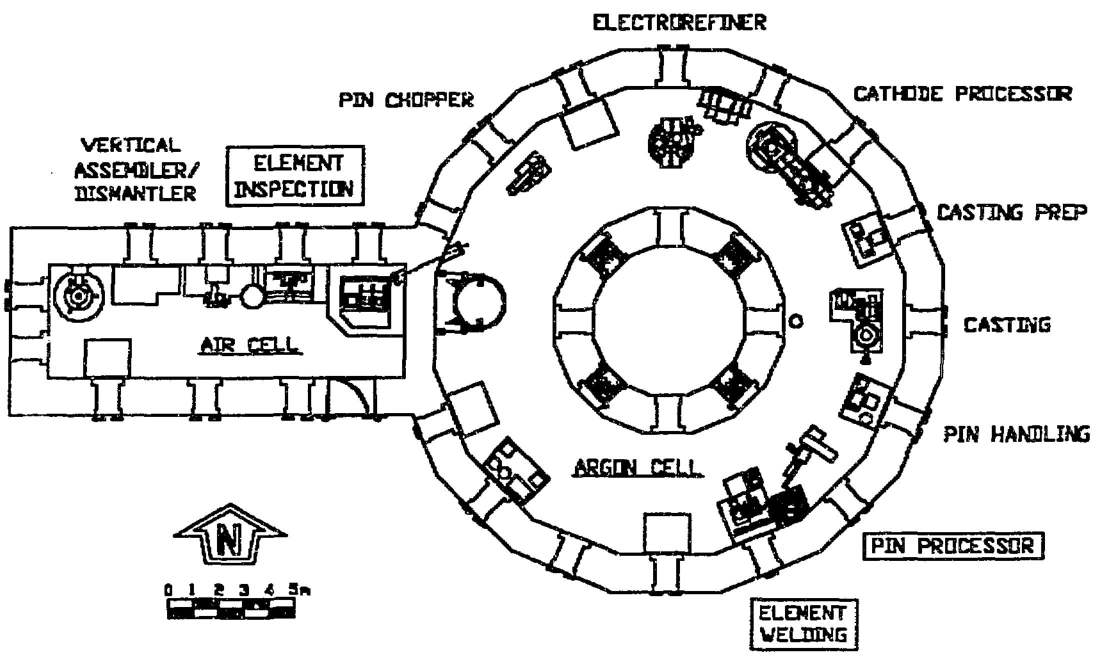

FIGURE 1 - AIR AND ARGON CELL EQUIPMENT LOCATIONS

The shielded repair area has 47 m^2 of remote or manual work space, wet and dry decontamination equipment, shielded and unshielded glovewall workstations, and a 4,500 kg capacity crane. Contamination control and ventilation are provided by the Air Cell exhaust system. The hot cells and repair area are connected by an air atmosphere transfer tunnel system with a component transfer envelope of 1.8 m diameter, 2.4 m height and 4,500 kg weight limit. No fuel or high level waste materials are handled in the repair area, although significant contamination levels are within the design basis for remote operations.

PROCESS DESCRIPTION

For the purposes of this and the following papers, the pyrochemical reprocessing technique that is the subject of this demonstration project can best be thought of in three parts:

1. The reprocessing steps, where spent fuel is chopped, dissolved in an electrolyte at elevated temperatures, and electrorefined to separate fuel constituents from fission products. The resulting fuel cathodes are distilled to remove electrolytes and process metals.

2. The fuel fabrication steps, where the ingots from the reprocessing steps are blended with various constituents from the recycle streams or makeup alloying elements, melted and cast into fuel pins, and then processed into completed fuel elements.

3. The fabrication support steps, where new fuel cladding jackets are prepared, loaded with bond sodium, and inserted in a handling magazine in an out-of-cell glovebox environment.

REGULATORY AND SAFETY ISSUES

The principal regulatory guidance for government-owned facilities of this sort is DOE Order 6430.1A (General Design Criteria), and the principal controlling permitting process beyond the DOE reviews and authorizations is the State level EPA permit.

DOE 6430.1A was at least partially written from the perspective of requirements for a glovebox facility, but it is being applied to the refurbishment of FCF and leads to several difficult problems in equipment and facility design. The key provision of the Order with respect to these problems is Section 1300-1.4.2 Accidental Releases:

> "Releases of hazardous materials postulated to occur as a result of DBAs shall be limited by designing facilities such that at least one confinement system remains fully functional following any credible DBA (i.e., unfiltered/unmitigated releases of hazardous levels of such materials shall not be allowed following such accidents."

This, in essence, is a requirement for "safety-grade" confinement of all radioactive or hazardous materials at either the process equipment, cell boundary, or pressure control system level.

There is no minimum source term of concern for accident scenarios specified in the Order, and hot cell reprocessing facilities would normally be assumed to be highly contaminated independent of the quality level required of the individual pieces of process equipment. We proposed that only process equipment containing significant quantities of radioactive materials at temperatures above their ignition points in a post-DBA air atmosphere should require safety-grade confinement, but the proposal was rejected by safety reviewers. The hot cell boundaries and confinement pressure control systems are largely redundant and seismically robust, but are not retroactively certifiable to current safety-grade criteria thirty years after they were designed and built. Therefore, a current-generation safety grade exhaust system (SES) and associated electrical supply were required for the Argon Cell to maintain a negative pressure differential and filtered exhaust even in a post-DBA situation. The system is activated by loss of differential pressure between the Argon Cell and the building basement. Differential pressure settings and Argon Cell seal pot overpressure relief system design are such that inadvertent activation of the system will not draw air into the Argon Cell.

An advantage of this design environment is that the individual items of process equipment may be designed to normal industrial codes for quality-sensitive components, and may be modified or replaced without requiring major review of the facility safety basis. A disadvantage is that potential air infiltration of the Argon Cell under post-DBA conditions must be assumed much sooner than it would under static conditions. Therefore, all exposed in-process materials that are potentially pyrophoric in an air atmosphere must be tracked and limited. A related problem is that these "at risk" materials must be isolated from the Argon Cell atmosphere in a timely manner any time the SES capability is compromised, such as for maintenance. This has had a major effect on the design of process equipment and process material storage systems.

The most important features of the air quality permit agreement are the requirements for current generation exhaust stack monitoring equipment and procedures, and a limitation on the amount of argon gas purge that is allowed through the Argon Cell. As described earlier, this cell is run largely in closed loop mode with minimal emissions. The purification system does not remove nitrogen or fission product gasses that accumulate from fuel element chopping, so the relative timing of chopping and purging operations affects radioactive emissions. The State has therefore imposed a very low limit on argon purge rate to limit radioactive emission rates regardless of the Argon Cell atmosphere inventory of fission gasses. This, in turn, requires stringent control of potential argon addition sources and precludes using externally-supplied argon for pneumatic applications as we have done in the past.

DEMONSTRATION PROJECT OBJECTIVES

A principal purpose of the demonstration program is to assess as best we can the commercial economics of this particular pyrochemical fuel cycle. This requires eliminating as many uncertainties as possible with respect to equipment scale, control systems, batch size, etc. The scale at which we have chosen to design is that associated with support of a 1400 Mwe reactor. Such a plant would require a throughput of approximately 100 kg HM per day and would have batch sizes in the various pieces of equipment in the 10 to 25 kg HM range. The EBR-II reactor, however, requires less than 200 kg HM recycle per <u>year</u>; hence equipment designed to commercial batch sizes will not be run at commercial utilization rates on the EBR-II throughput. We have backlogged considerable EBR-II spent fuel, so we will be able to run at high throughput for brief periods. Considerably more effort has been devoted to integrated control systems and modular maintenance principles than would be typically expected of such low utilization equipment.

EFFECTS ON EQUIPMENT DESIGN

The dominant requirements of the current design environment with respect to process equipment in general and automated fuel fabrication in particular are as follows:

1. Minimum out-of-secure-storage exposure times and easiest possible isolation methods for all in-process materials.

2. Priority for materials with highest potential for pyrophoric behavior in an air atmosphere.

3. Minimum potential cell boundary air in-leakage area under DBA conditions. Because of the redundancy and environmental qualification requirements for active components in a safety-grade isolation system, this criteria basically precludes out-of-cell vacuum, pneumatic, or fresh argon supply systems except where absolutely required. We have implemented a small scale argon pneumatic system that draws from and exhausts to the general Argon Cell atmosphere in order to simplify compliance with this requirement and the State limit on argon purge rate.

The net effect of these requirements has been to force the fuel fabrication system into easily isolated containers for storage and basic handling operations throughout the fuel element fabrication process. The fuel handling magazine had independently evolved as an easily-isolated design for the following reasons:

1. High-integrity isolation of the sodium-loaded jackets in an air or vacuum environment was required by process design.

2. The design intent to allow fuel element wire wrap prior to end plug welding required some degree of isolation of the assembled jacket from the contaminated fuel loading environment.

The basic magazine approach to fuel element handling was forced by the precision location requirements of the various prices of fuel fabrication equipment to be discussed later in this session. The magazine must also allow the fueled section of the elements to be heated to 500°C in the fuel settling and thermal bonding step. The design is shown in Figure 2.

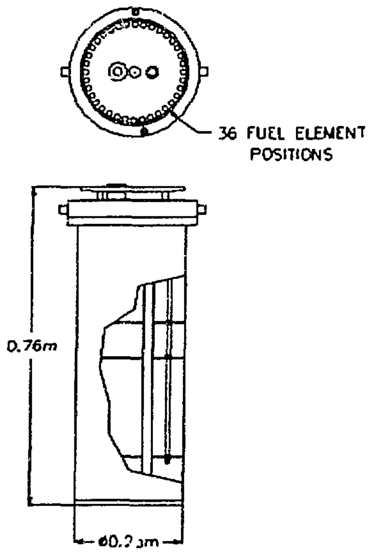

FIGURE 2 – ELEMENT FABRICATION MAGAZINE

The individual process equipment systems have generally been designed to batch sizes that are limited by criticality or passive cooling concerns; i.e., there are few further economies of scale available to a commercial plant. Fuel material and component handling, however, has not been attempted at commercial scale due to inherent limitations in the 1960's-era overhead handling systems and non-prototypic size of the EBR-II fuel elements. Major improvements in this area would be possible. Automated handling systems would allow much more rapid transfers to and from storage, with significantly less intermediate staging of materials. The fuel element handling magazine contains only 36 jackets because of the relatively small transfer lock to the Air Cell and a minimum jacket spacing requirement for the welder ground clamp. Pre-assembled cladding rows or bundles and end-on laser end cap welding could markedly increase this number. A certifiable safety-grade cell boundary would markedly decrease concerns about fuel material temperatures and pyrophoric behavior. This in turn would ease material tracking requirements and decrease the need for rapid equipment cleanout of process materials. The combined effect of these changes would significantly decrease the number of handling operations, increase the speed of individual operations, and perhaps even get handling operations off the critical path in process design and optimization.

Acknowledgements - This work was supported by United States Department of Energy under Contract 31-109-ENG-38.

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