DESIGN OF THE MOX FUEL FABRICATION FACILITY

James V. Johnson
MFFF Technical Manager
U.S. Department of Energy
1000 Independence Avenue
Washington, DC 20585
(202) 586-5960

Edward J. Brabazon
MFFF Engineering Manager
Duke, Cogema Stone & Webster
400 South Tryon Street
Charlotte, NC 28202
(704) 373-7959

ABSTRACT

A consortium of Duke Engineering and Services, Inc., COGEMA, Inc. and Stone & Webster (DCS) are designing a mixed oxide fuel fabrication facility (MFFF) for the U.S. Department of Energy (DOE) to convert surplus plutonium to mixed oxide (MOX) fuel to be irradiated in commercial nuclear power plants based on the proven European technology of COGEMA and BELGONUCLEAIRE. This paper describes the MFFF processes, and how the proven MOX fuel fabrication technology is being adapted as required to comply with U.S. requirements.

1. INTRODUCTION

The Office of Fissile Materials Disposition (MD) is now part of the DOE National Nuclear Security Administration (NNSA). The goal of the Fissile Materials Disposition Program is to reduce the global nuclear danger of surplus weapons-usable fissile materials through strategies and actions to provide safe, secure, cost-effective and inspectable storage of U.S. weapons-usable fissile materials, and to dispose of these surplus materials in accordance with terms set forth in agreements between the United States and Russia.

DOE is charged with the task of disposing of 50 metric tons of U.S. weapons-grade plutonium, and is pursuing an approach that will render the plutonium inaccessible and unattractive for future weapons use. A key element of the overall strategy is the conversion of 33 metric tons to mixed oxide (MOX) fuel that can be safely used to generate electricity at commercial nuclear power stations. Mixed-oxide is a blend of uranium and plutonium oxides, which is fabricated into assemblies suitable for use in nuclear reactors. Mixed-oxide fabrication facilities have operated successfully in Europe since the 1960's.

The consortium for the project was selected by DOE based on its proven technology. The consortium includes Duke Engineering & Services, Inc., COGEMA, Inc., and Stone & Webster (DCS), the owners of the Limited Liability Company to execute the project, and three major subcontractors, Duke Power, Framatome ANP and Nuclear Fuel Services (NFS). In addition, BELGONUCLEAIRE is a principal subcontractor to COGEMA. The MOX fuel to be produced in the MOX fuel fabrication facility (MFFF) will be irradiated in four Duke Power, with Electricité de France (EDF) support to give DCS the benefit of the European experience with 34 reactors loaded with MOX fuel.

The contract was awarded in March 1999. The base contract is to design and license the MFFF and to perform fuel qualification, and planning for irradiation services and transportation. Option 1 is to manage construction and startup the MFFF and make modifications to the mission reactors. Option 2 is to operate the MFFF and to irradiate the MOX fuel in the mission reactors. Finally, Option 3 provides for MFFF deactivation.

2. MOX FUEL FABRICATION FACILITY

The MOX fuel fabrication facility (MFFF) will be designed to dispose of 33 metric tons (MT) of plutonium. The MFFF is based on the successful COGEMA Melox plant at the Marcoule site in southern France. In addition the plant will include an aqueous polishing feature, based on COGEMA experience at the La Hague facility in northern France. The process design is performed by a joint team of the COGEMA group and BELGONUCLEAIRE engineers. The facility design and Americanization of the process design is conducted by the Duke Engineering and Stone & Webster engineering team.

The project design schedule is a 39-month schedule starting in March 1999 and finishing in June 2002. The facility will be licensed by the NRC, and owned by DOE. To support construction and operation schedules, the NRC application for construction authorization was submitted in February 2001. Supplemental information will be provided as the design evolves. Final license application is planned for 2002. Construction is scheduled to start in 2003, and plant startup is scheduled for 2006. The first fuel from the plant would be delivered to the mission reactors in 2007.

The MFFF has two major process operations, the aqueous polishing process, primarily to remove gallium from the plutonium, and the MOX fuel fabrication process that processes the oxides into pellets and manufactures the fuel assemblies. The main steps in the aqueous polishing and MOX processing operations are shown in Figure 1 – Aqueous Polishing and MOX Process Main Steps.

A. AQUEOUS POLISHING PROCESS

The aqueous polishing process involves three major steps. These are: Dissolution, Purification, and Conversion. The steps in the aqueous polishing process are further broken down in figure 2 – Aqueous Polishing Process. The following is a summary of the major steps and features of the aqueous polishing process:

- PuO_2 Dissolution by electro-generated Ag (II)

The dissolution step involves silver catalyzed dissolution and filtration. The process was selected because it is very efficient, and independent of PuO_2 powder characteristics. It results in the complete dissolution of the PuO_2 powder according to kinetics governed solely by the rate of Ag (II) generation. PuO_2 powder is dissolved by electro-generated Ag (II) in a nitric acid medium.

- Pu Purification by solvent extraction

The purification step involves Plutonium extraction, solvent regeneration, acid recovery and silver recovery. The process was selected because it yields very little Pu leakage and has a very high gallium decontamination factor. The main functions of the plutonium extraction step are: Plutonium extraction and impurities scrubbing and plutonium stripping. These operations are performed in pulsed columns.

- Conversion into PuO_2 by oxalate calcination

The conversion process is a continuous oxalate conversion process. The process was selected because it yields a PuO_2 powder routinely used for MOX fabrication at COGEMA facilities. Conversion to plutonium oxide several main operations: precipitation, evaporation of the mother liquor, filtration, drying and calcination and plutonium conditioning.

B. MOX

The A-MIMAS process is the most recent evolution step of the fabrication processes adopted *by BELGONUCLEAIRE and COGEMA to* produce pellet fuel characterized by an intimate mix of the PuO_2 and UO_2 powders.

The fuel fabrication process includes four major steps, the powder master blend and final blend production, pellets production, rods production and fuel rod assembly. The steps for the MOX process are shown in Figure 3 – MOX Process and Figure 4 – MOX Process – Powder Area Main Equipment. The individual steps of the MOX fabrication process are as follows:

- Powder master blend and final blend.

The first operation of blending in the A-MIMAS process is the production of the Master Blend with 20% Plutonium content, which is higher than the content in the final blend. Three different powders are blended: PuO_2, UO_2 and recyclable scraps of MOX fuel pellets. Primary milling is one of the most important processes and the ball mill is the best device to meet all the requirements necessary to obtain a good Master blend before sieving and final blending. The final blending is the last operation of the A-MIMAS process to obtain the final Pu content adjustment. After the final blending, the Master blend and the dilution UO_2 are homogenized to satisfy the stringent requirements of MOX fuel pellets.

- Pellet Production

In this step of green pellet production, most of the final characteristics are defined. In order to avoid pellet defects, the parameters of the pelletizing operation must be adjusted and controlled. By-products such as recovered powder and discarded pellets are recycled. This includes crushing and ball milling of the discarded pellets, and pelletizing and sintering recovered powder before following the same processing as the discarded pellets. The sintering step removes organic products dispersed into the pellets and removes the poreformer necessary to reach the required pellet specific gravity. The dry centerless grinding machines grind the sintered pellets to the final diameter. The system also handles the discarded pellets and the dust coming from the grinding process.

- Rod Production

Rods are loaded to an adjusted pellet length column, TIG welded, helium pressurized and then decontaminated. Rod inspection then verifies the helium tightness, the welding quality, and the correct Pu content in the pellet column. The rods are submitted to geometrical and visual inspections.

- Fuel Rod Assembly

Rods of required different Pu content are assembled and the final bundles are stored before packaging and shipping.

3. DESIGN

There are a number of challenges associated with the design of the MFFF. It is a facility using weapons-grade plutonium as the feedstock, it is owned by the U.S. Department of Energy and licensed by the U.S. Nuclear Regulatory Commission, and involves the transfer of technology from Europe to the United States. Several of the challenges are discussed as follows:

A. NRC LICENSING

The MFFF will be a DOE-owned, contractor-operated facility, collocated with other DOE-owned facilities at the Savannah River Site (SRS). The MFFF is subject to NRC regulation. DCS generally will select standards on a hierarchical basis that demonstrate compliance first with NRC requirements, then with DOE, EPA, OSHA, state, and local requirements. The reason for the establishment of such a hierarchy is that compliance with NRC requirements is a condition of the NRC license. Further, many requirements, such as DOE, and certain OSHA, EPA, and IAEA requirements, may be implemented directly through compliance with NRC requirements.

Licensing for the MFFF will be in accordance with 10 CFR 70, Domestic Licensing of Special Nuclear Material. The recent changes in the rule differ significantly from the previous version of 10 CFR 70.

The requirements in 10 CFR 70 place a heavier burden on applicants for plutonium facilities than for other fuel cycle facilities. Authorization to start construction and issuance of a possession-and-use license are considered separate licensing actions (or, at a minimum, distinct steps in an ongoing licensing action). DCS submitted a request for construction authorization, and subsequently will submit a license application for possession and use of SNM. The construction authorization request included design basis information and a safety assessment, a QA program description, and an Environmental Report. The construction authorization request requires that the NRC perform reviews (with any required hearings) with regard to environmental protection, and will request NRC approval of the design basis and QA program. Subsequently, DCS will submit the license application, and a separate NRC review will take place, presumably resulting in issuance of a possession and use license.

DCS began technical exchanges with the NRC on several issues and provided some design basis and QA program information early, in advance of the formal request for construction authorization.

B. SAFETY ASSESSMENT / INTEGRATED SAFETY ANALYSIS

An Integrated Safety Analysis (ISA) is being prepared for the MFFF to establish the facility safety design basis and to support the NRC 10 CFR 70 licensing requirements. The ISA process is a set of systematic analyses to identify plant and external hazards and their potential for initiating accident sequences; the potential accident sequences; their likelihood and consequences; and the items (structures, systems, and components and activities of personnel) that are relied on for safety (IROFS), i.e., to prevent or mitigate such accidents.

As a starting point for identifying the hazards for the MFFF, an initial hazard list based on general safety principles applicable to COGEMA facilities (mainly the Melox facility) was used and then adapted for US regulations and standards. The initial step in the ISA process is the preparation of a Safety Assessment (SA), to identify and screen hazards (see Figure 5). The SA provides a qualitative assessment of postulated accident scenarios in the MFFF and identifies an initial set of Items Relied on for Safety (IROFS). The SA team consists of analysts experienced in the SA methodologies with extensive NRC and DOE experience, who have a thorough understanding of the process systems, operations, and hazards. In later phases, other methods such as Hazard and Operability Analysis (HAZOP) and Fault Tree Analysis will also be employed to analyze areas in more detail. The ISA is a living document to be utilized during construction and throughout the life of the facility to evaluate potential plant changes, monitor plant performance, and ensure configuration management (see Figure 6).

C. CRITICALITY CONTROL

The following approach to nuclear criticality safety is being used for the design and safety analysis of the MFFF. The criticality safety evaluations are being performed in accordance with standard US industry procedures and methodologies and are based on the criticality standard ANSI/ANS-8.1. The US standard criticality code KENO and the 238-group cross sections, included as part of the standard SCALE 4.4 package, will be utilized.

Calculations will be made based in particular on benchmarks using standard methods in which administrative margin, bias, and uncertainty will be applied to the calculated subcritical k-effective. A credible worst-case treatment and/or statistical accounting will be performed for mechanical, material, and fabrication uncertainties.

Using MFFF criticality safety design principles, the facility is divided into criticality control units. For each unit, the reference fissile medium is defined along with the criticality control mode. Geometry control is used whenever possible. Fissile material mass along with moderation control will be employed when required for process and operability reasons. The double contingency principle is applied at all times. This requires at least two unlikely, independent, and concurrent changes in process conditions before a criticality accident is possible.

Appropriate criticality benchmark experiments will be employed for each type of physical situation in the MFFF. This is important given the range of diversity in MFFF applications including high, medium, and low moderated PuO_2 and mixed oxide powder, nitrate, oxalate solutions, and arrays of pellets and rods. Benchmark experiments will come primarily from the international criticality benchmark handbook although some additional recognized experiments are expected to be used. Validation of benchmark experiments is expected to be performed using traditional statistical methods along with newly developed methods if necessary and available.

Criticality safety administrative, QA, and Training programs using industry standards along with operational inspections, audits, assessments, and investigations will be regularly performed in accordance with standard criticality safety principles

D. STATIC & DYNAMIC CONFINEMENT SYSTEMS

The confinement systems are designed to prevent any permanent contamination in the areas where personnel can be present and to limit releases to below acceptable limits in the event of an accidental release, spill, or system failure.

Multiple tiers of confinement systems are used in the design of this facility. Each confinement system consists of static confinement and dynamic confinement subsystems. The static confinement systems include building walls, barriers, glove boxes, enclosures, filters, hoods, piping, tanks, valves, exhaust ductwork, plenums, and vessels. The dynamic confinement systems consist of the HVAC exhaust subsystems. The dynamic confinement systems supplement the static confinement systems by maintaining pressure gradients between the different confinement zones to induce airflow leakage from the zones of lowest contamination potential toward the zones of increasing contamination potential.

The dynamic confinement portion and the static containment portion of the Confinement Systems complement the functions of each other. The confinement systems include: a first (primary) confinement system consisting of glove box systems and vessels, tanks and piping for aqueous polishing, and the very high depressurization exhaust system. A second (secondary) confinement system consists of rooms and associated ventilation exhaust systems that confine any potential release of hazardous material from the primary containment. This system can comprise one or two static barriers depending on the case. Typically these areas are served by high and/or medium depressurization exhaust systems.

E. INTERFACE WITH PDCF

The MFFF will receive PuO_2 from the Pit Disposition and Conversion Facility (PDCF) in containers that meet DOE standards. The PuO_2 will meet specification requirements of DCS, and will be shipped by methods that ensure the security of the material, under DOE authority until inside the MFFF secured area. Both the PDCF and the MFFF will provide for sufficient storage of PuO_2 to ensure a continuous flow to the MFFF to satisfy the demand curve for the material. In order to ensure communication with the PDCF project, a controlled interface document is maintained by DOE, and periodic interface meetings are held between the two projects.

F. DESIGN REVIEWS

The final design of the project will complete the design documents necessary to procure equipment and construct the project. The design documents will be assembled into bid packages based on the overall procurement strategy of the project. During final design, there will be two formal design reviews, one at 30 percent completion of final design, and one at 85 percent completion of final design. The design reviews will include both DOE and DCS personnel, and will include both vertical and horizontal slices of the design. This review will include topics such as confinement, criticality, seismic design, fire protection, material control and accountability, electrical power, control systems and the integrated safety assessment. Other technical meetings and reviews are scheduled as appropriate.

G. PROCUREMENT OF PROCESS EQUIPMENT

As the MOX manufacturing process is a new process to the United States, it is logical that some of the process equipment may be more readily available in Europe or from vendors previously used by COGEMA and BELGONUCLEAIRE. Key items of equipment (i.e. homogenizer, pelletizer, and sintering furnace) are critical to the reliability and operation of the MOX process. The procurement sources will be analyzed for the most favorable condition for the MOX project with regard to responsiveness, reliability, time frame, availability etc.

MFFF equipment will be specified on the basis of detailed design and performance requirements. Acceptance of the equipment will require functional demonstration of the equipment's capabilities. Process performance requirements will be provided in detail, as will layout configurations, geometrical interfaces, major equipment items, and standard glovebox component assemblies.

Formal acceptance test programs implemented at the vendor's facility will be required which demonstrates not only all process-related operations, but glovebox functional capabilities and compliance with maintenance requirements as well. Process operations will be demonstrated by physically exercising the equipment with surrogate materials. Glovebox functional capabilities will be demonstrated by leakage tests conducted both in the vendor's facility and in the plant.

SUMMARY

In summary, the MOX product is strategically important to the United States. DOE selected the DCS team based on its combined expertise and proven technology. The DCS team will build upon the experience of the Melox and La Hague facilities, and incorporate requirements of the NRC, DOE and other U.S. agencies, regulations and codes and standards. The aqueous polishing process and the MOX process have been selected for the MFFF. The NRC Licensing, Safety Assessment / Integrated Safety Analysis, Criticality Control, Static & Dynamic Confinement Systems, Interface with PDCF, Design Reviews and Procurement of Process Equipment, are representative of design efforts ongoing on the project.

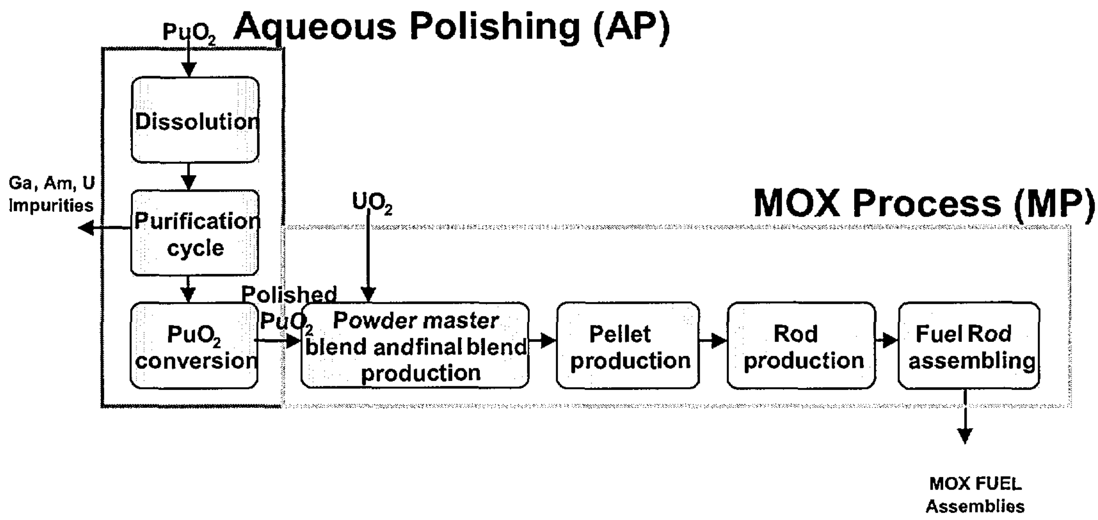

Figure 1 - Aqueous Polishing and MOX Process Main Steps

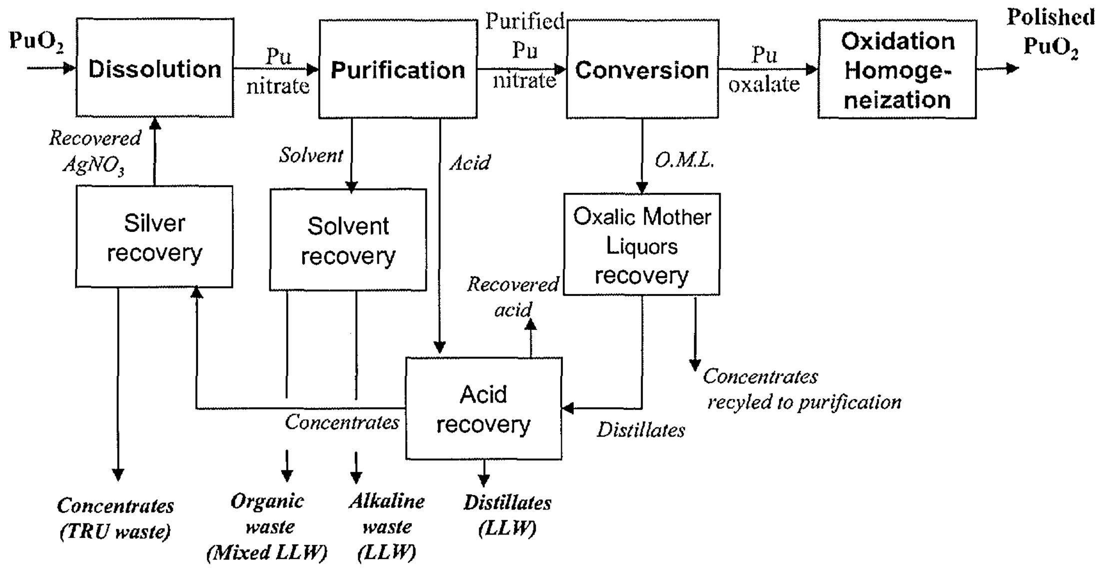

Figure 2 - Aqueous Polishing Process

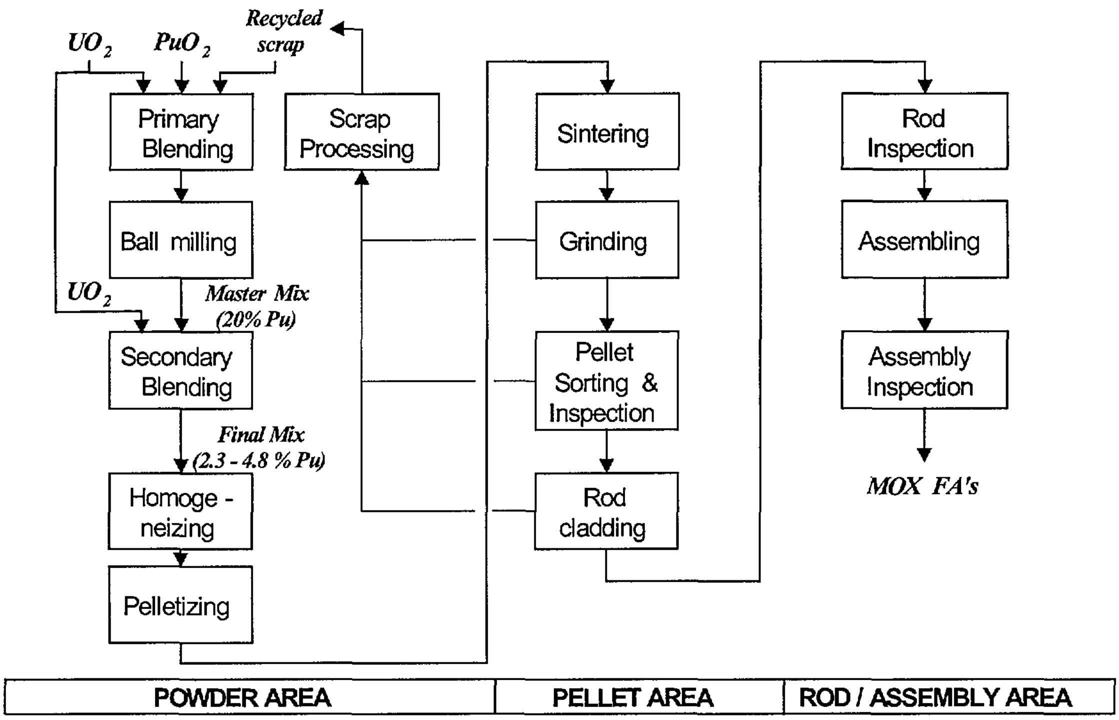

Figure 3 - MOX Process

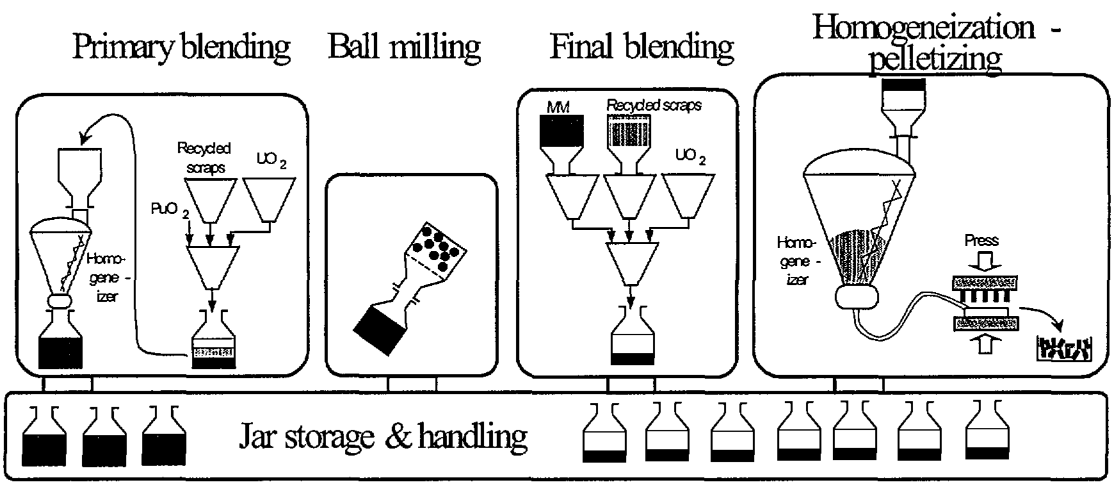

Figure 4 - MOX Process - Powder Area Main Equipment

Safety Assessment of the Design

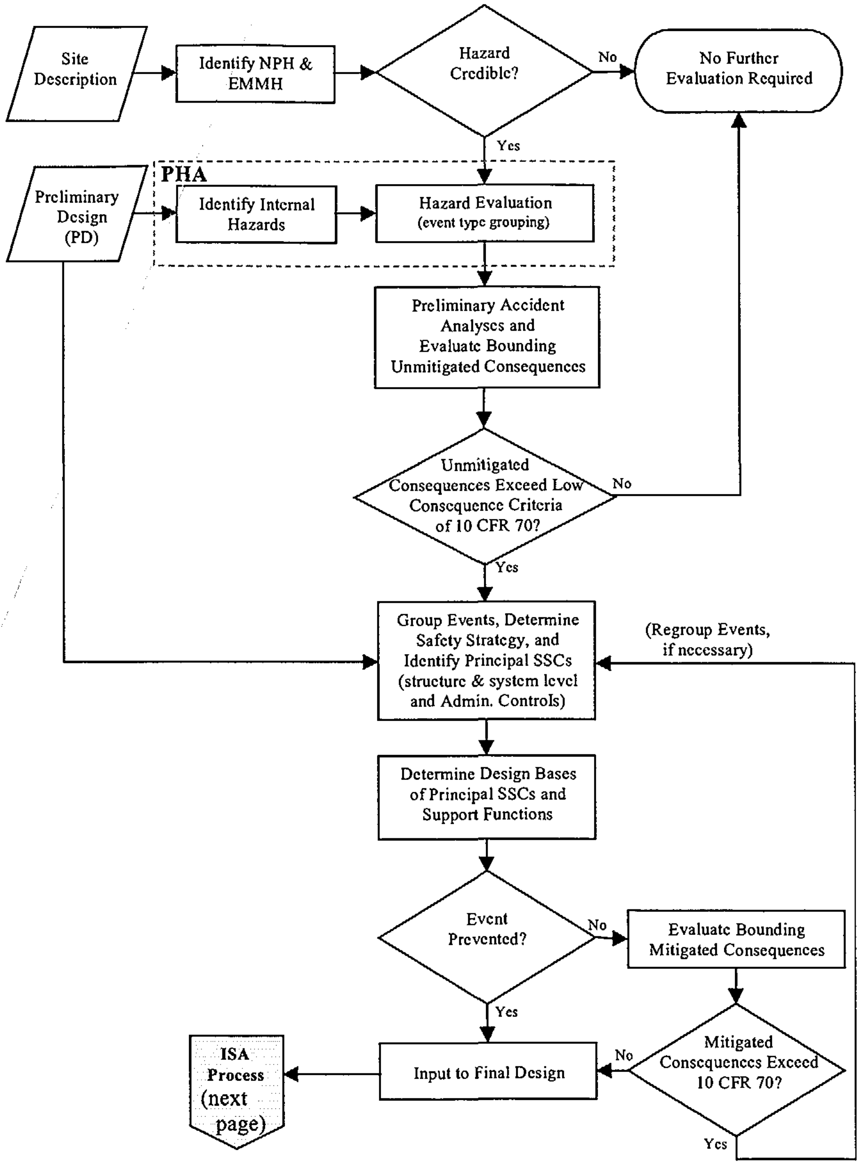

Figure 5 - Safety Assessment

Latter Phase of Integrated Safety Analysis

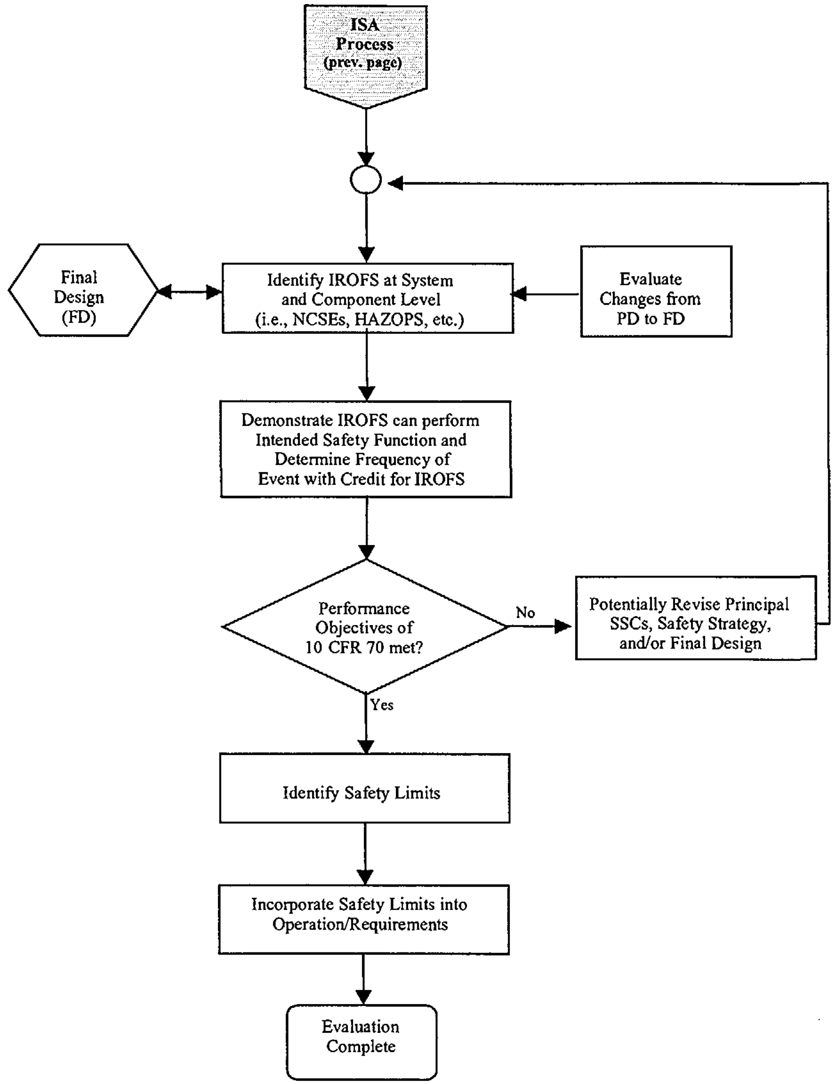

Figure 6 - ISA Flow Chart (Latter Phase of ISA)