WASTE MINIMIZATION, RECYCLING AND REUSE CONSIDERATIONS FOR THE DESIGN OF A NUCLEAR FUEL AND TARGET FABRICATION PLANT

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ABSTRACT

Fluor Daniel, Inc. (FDI) was awarded a contract by the U.S. Department of Energy (DOE) to design a Fuel and Target Fabrication Facility (FTFF) for the New Production Reactor (NPR) Program. A significant element of the design was waste minimization using the approaches of source reduction, direct reuse, and recycle and responsible waste management. Process feed and process effluent streams quantities and compositions were either analytically determined or estimated. Industry proven and emerging selective, high efficiency technologies were identified for process effluent stream treatment. These were evaluated using a broad range of criteria. A modified Kepner-Tregoe methodology was used to evaluate and rank the effluent stream/disposal process options. A waste minimization team consisting of process, chemical and environmental engineers was used to determine the technology application and the process maturity. It was determined that viable processes were not available for treatment of all of the process streams. Where viable treatment processes were available, it became clear that multiple equipment pieces would have to be integrated into a processing system. Process/equipment design, equipment development and pilot plant testing of emerging processes and equipment is required.

In the evaluation and ranking of the process options, some of the category weighted scores were similar in numerical value. This approach identified areas where further characterization of the process effluent streams is needed and/or additional process option data are required.

INTRODUCTION

Fluor Daniel, Inc. (FDI) was awarded a contract by the DOE early in 1990 to design a Fuel and Target Fabrication Facility (FTFF) under the NPR Program. The FTFF was intended to support the Modular High Temperature Gas Cooled Reactor (MHTGR) Project technical option by supplying the initial reactor cores and core reloads for a four-module plant (1400 Mwt). The reactor cores are graphite and contain enriched uranium and lithium distributed in a graphite matrix. The FTFF was to be co-located with the reactors and other supporting facilities. The reference site is the Idaho National Engineering Laboratory (INEL) in Idaho Falls, ID.

DOE's "Waste Reduction Policy Statement" requires all DOE Program Offices and Field Operations to "institute a waste reduction policy to reduce the total amount of waste that is generated and disposed of by DOE operating facilities through waste minimization (source reduction and recycling) and waste treatment." The policy consolidates several DOE Orders (1,2,3) and requires waste reduction to be a "prime consideration" in research activities, process design, new facility design, construction, operations and decontamination and decommissioning.

This DOE policy directive has been required in order to respond to: 1) a need to satisfy permitting requirements on its projects, 2) increasingly stringent environmental standards being applied to all processing activities and 3) emphasis on source reduction and recycling as contrasted to waste generation and treatment.

SCOPE OF THE DESIGN WORK

FDI prepared conceptual and Title I designs for an NPR FTFF. This facility was to house a fuel (uranium) and a target (*lithium*) process line(s) provided by process demonstration contractors (General Atomics, Babcock & Wilcox and Nuclear Fuel Services, Inc.). Nominal plant production rates were 880 fuel element assemblies and 11,520 target elements per year. The components and configuration of the fuel and target elements are shown in Figs. 1 and 2. The FTFF facility includes Fuel, Target, Operations and Plant Service Buildings with 200,000 square feet under roof. An Auto CAD simulation model enhanced with ASG was used as a design tool. A 3D FTFF facility model produced using this software is illustrated in Fig. 3.

The primary process lines involved complicated chemical processes to produce the uranium oxycarbide (UCO) and lithium aluminate (LiALO8) materials under stringent quality control. The process designs were the responsibility of the process development contractors. The processes included a large number of chemical feed and recycle streams and produced about 30 effluent streams. FDI had the design responsibility for buildings, all process effluent control and waste management including reduction in waste volume, toxicity and mobility. This division of responsibilities created a complicated interface between FDI and the process development contractors. A fuel kernel forming and washing process block flow diagram with feed input and process effluent streams is illustrated in Fig. 4. The major constituent of process effluent stream from these operations is trichloroethylene (TCE) contaminated with formaldehyde and uranium. The conceptual process design proposed for the recycle of the TCE and disposal of uranium and formaldehyde is shown in Fig. 5.

ENVIRONMENTAL DESIGN REQUIREMENTS

The principal design requirements for the FTFF from conceptual design through decommissioning are stated in DOE FTF-RD-0001, Rev. 0 (4). The four fundamental environmental design requirements are the following:

- <u>FULL COMPLIANCE.</u> The FTFF facilities will be designed, constructed, tested and operated in full compliance with all applicable federal, state and local statutes and regulations as well as DOE and Executive Orders for protection of the environment and worker health and safety

- NATIONAL ENVIRONMENTAL POLICY ACT (NEPA). The design, construction and operation of the FTFF facilities shall be in full compliance with the letter and spirit of the NEPA, including specific environmental mitigation commitments
- ENHANCED ENVIRONMENTAL, HEALTH AND SAFETY COMPLIANCE AND MONITORING. All New Production Reactors facilities will, to the maximum extent practicable, be designed, constructed, operated, decontaminated and decommissioned to integrate the fundamental goals of 1) minimization of the discharge of all pollutants to as low as reasonably achievable levels, 2) minimization of waste generation through source reduction, recycling, and waste treatment, and 3) minimization of exposures to worker and the public to all radiological and non-radiological hazards and will be designed to utilize real time monitoring as a tool for minimizing environmental impacts
- REAL TIME MONITORING. In addition to monitoring required under federal, state, and local regulatory authority, continuous monitoring of gaseous and liquid effluents, where practicable, or discrete emission monitoring, as appropriate, shall be included in the design and operation of all FTFF facilities for all known and potential pollutants and hazardous emissions.

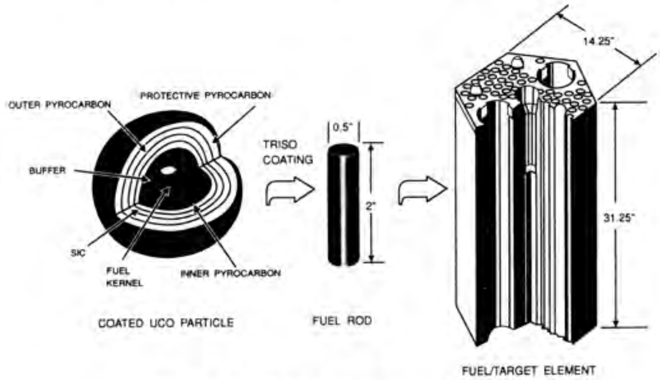

Fig. 1. Fuel element assembly.

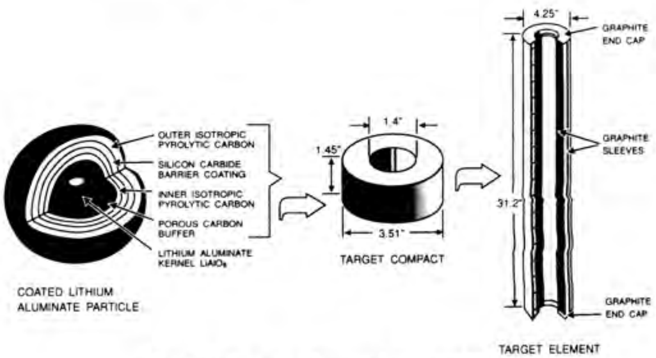

Fig. 2. Target element assembly.

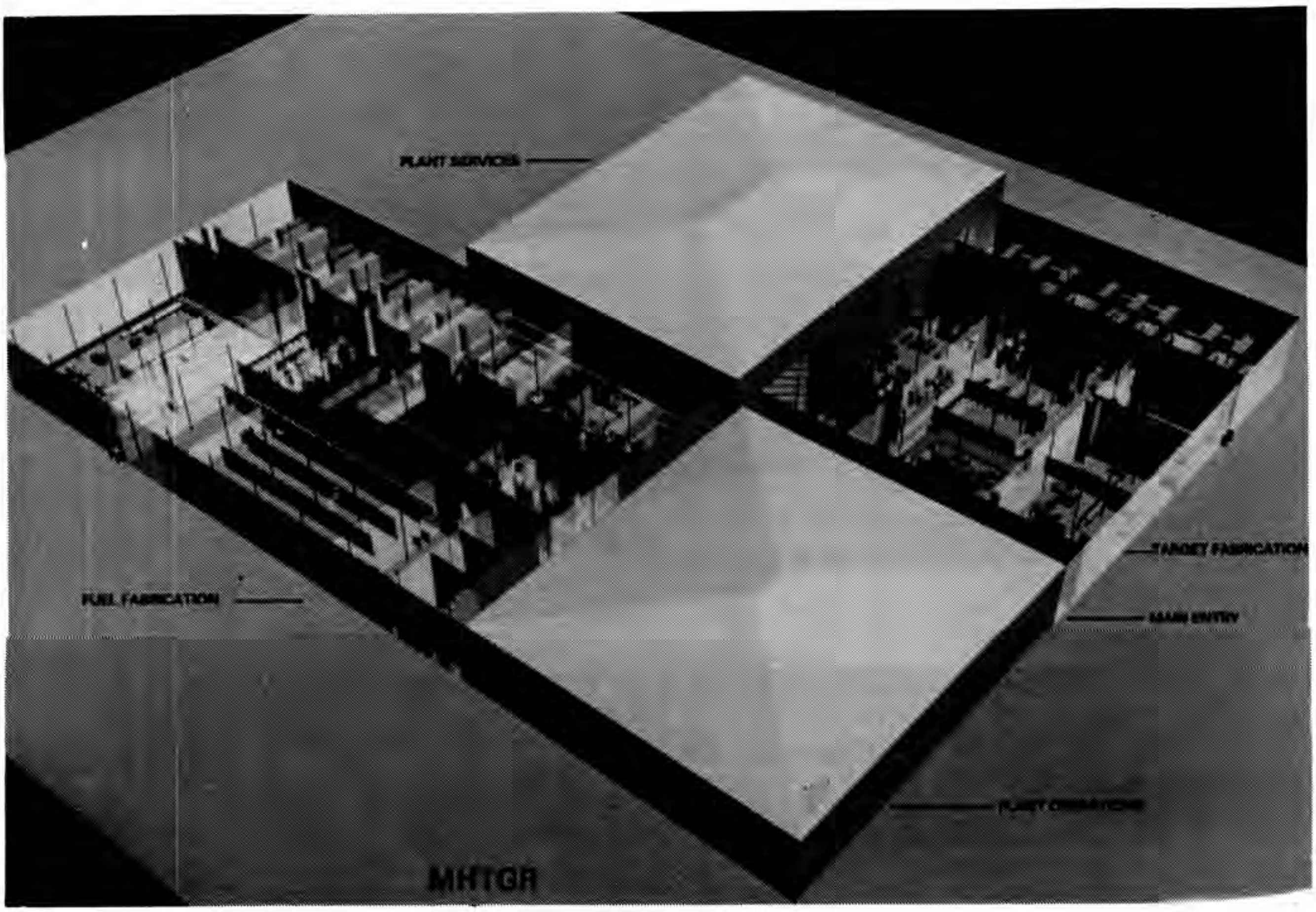

Fig. 3. MHTGR.

The DOE NPR Program adopted "zero discharge" as a goal for liquid process effluents for the FTFF facilities at the reference (INEL) site.

WASTE MINIMIZATION AND POLLUTION PREVENTION AWARENESS PLAN AND DESIGN REPORT

The FDI scope of work included the preparation of a Waste Minimization and Pollution Prevention Awareness Plan (WMAPPA) and a Waste Minimization and Pollution Prevention Design Report (WMAPPD). A U.S. DOE, Model Waste Minimization and Pollution Prevention Awareness Plan (5) was used as guidance.

The WMAPPA plan defined the organization, effort and resources required to systematically incorporate source reduction of hazardous, mixed and radioactive waste generation in the MHTGR-FTFF Title I design. For those effluents that cannot be eliminated, reduced or recycled and become wastes, process designs were prepared for treatment to reduce waste volume, toxicity and mobility before storage or disposal. The overall benefits of the pollution prevention program are shown in Fig. 6 and the FDI organizational structure to implement and achieve these benefits is shown in Fig. 7.

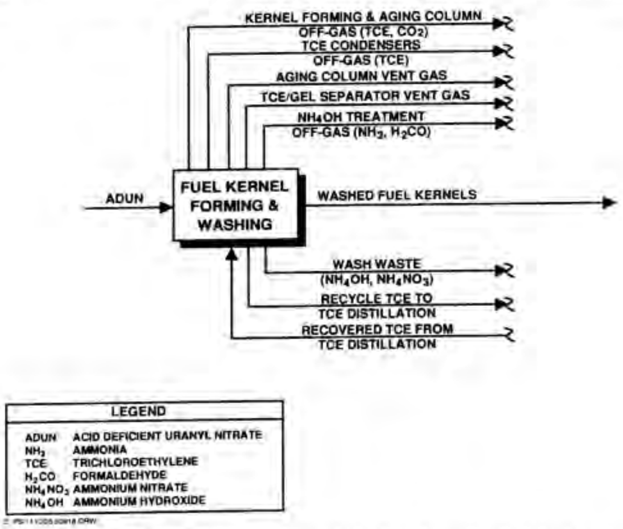

Fig. 4. MHTGR-FTFF waste minimization fuel fabrication block flow diagram.

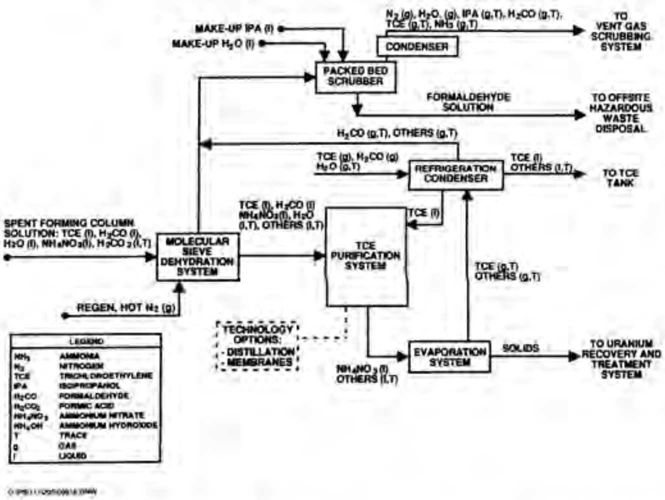

Fig. 5. MHTGR-NPR fuel process waste min. option LF1 TCE recovery and purification system.

The WMAPPD report was prepared in response to the Pollution Prevention Act of 1990 (6) and the DOE NPR Waste Minimization and Pollution Prevention Awareness Program. The report focused on five major issues:

- Regulatory assessment over the next decade
- Waste minimization strategies, specifically, source reduction to respond to long-range regulatory assessment
- Identification of process effluent stream recovery and waste disposal options and the quantities and composition of the FTFF process effluent streams

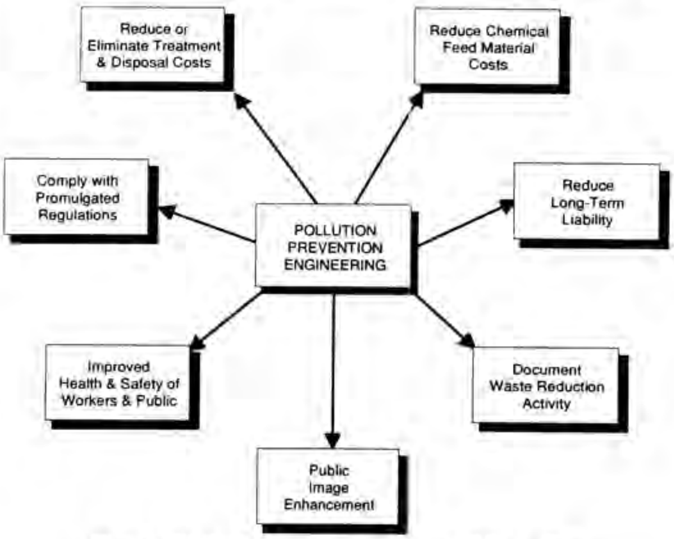

Fig. 6. Pollution prevention overall benefits.

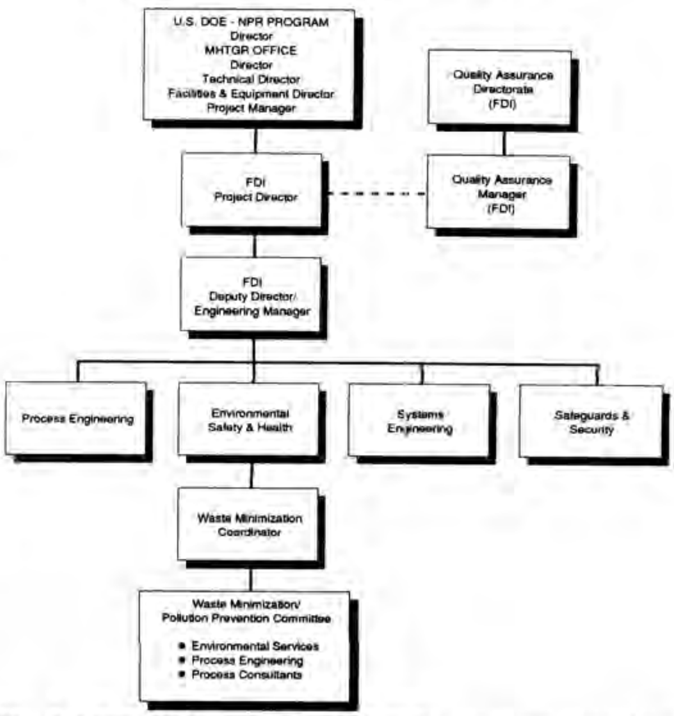

Fig. 7. MHTGR-FTFF Title I-WMPPA program organizational chart.

- Methodology for the evaluation and prioritization of effluent processing and waste minimization disposal options
- Design data needs (DDN) for emerging processing technology, interface control with process design contractors and pilot testing for qualification of the process options

METHODOLOGY FOR OPTION EVALUATION

A modified Kepner-Tregoe methodology was used for the evaluation and prioritization of the effluent processing and waste minimization options. The ranking system used to prioritize the options was based on four broad categories, i.e., 1) technical, 2) institutional and environmental, cost and 4) production cost avoidance.

Within each category there are several criteria that were used to evaluate the process effluent recovery and waste treatment processing options.

For illustrative purposes, some examples of the criteria within each category are cited below.

- Technical
  - feasibility
  - reliability
  - ability to adjust to process changes
  - complexity of pilot testing
- Institutional and Environmental
  - ability to reduce future treatment
  - system permitting/regulatory difficulty
  - eliminate or reduce the generation of hazardous/radioactive waste
- Cost
  - design and development cost
  - system capital and installation cost
  - startup and shakedown cost
  - operation and maintenance cost
- Production Cost Avoidance
  - on-site capital required for treatment
  - on-site operations and maintenance cost
  - off-site treatment and disposal cost
  - feed cost avoided by chemical recycle

Although the criteria in the categories are subjective, they offered the most reasonable approach to prioritizing the waste minimization processing options. As the FTFF process design is established, these waste minimization design options become more definitive.

These criteria were used to evaluate each option only as it relates to the fabrication processes in the FTFF. The options were not evaluated against each other, therefore additional options can be included at a later date with previously ranked options. The waste minimization reduction option ranking is the summation of the weighted individual category numbers.

The point system used involved assigning values of 1 to 10 to each criterion based on the attributes of the waste minimization option. The value assigned to a criterion was >5 if beneficial, <5 if detrimental and 5 if inconsequential.

In order to reflect the importance of different criteria with respect to each other, a weighting factor was assigned to each criterion within each category. The product of the criterion score and the weighting factor resulted in a weighted score. The weighted scores within a category, for example, Technical, were summed. The four categories were also assigned a weighting factor to reflect their relative importance. Again the product of category score and the weighting factor resulted in a category weighted score. The sum of the weighted category scores gave a numerical value to rank and prioritize the waste minimization options. The scoring of the process effluent recovery and waste minimization treatment options was time-consuming since there were 14 target and 15 fuel waste minimization treatment options and each was evaluated against 28 criteria. After applying this ranking methodology, some of the overall weighted category scores had very similar numerical values. This approach identified areas where no definitive choice of waste minimization option could be made. Therefore further characterization of the process effluent stream is needed and/or additional details about the effluent treatment process and equipment are required. Also, the ranking methodology gave the pollution prevention engineers the opportunity to revisit the ranking criteria to ascertain where an effluent treatment process was strong or deficient relative to a particular criterion.

CONCLUSIONS AND OBSERVATIONS

Several issues surfaced during the evaluation of the options to treat the process effluent and waste streams. These issues are discussed below.

- Commercially viable processes are not available for the reclamation of all effluent streams and integration of equipment into operating systems is required.
- Conventional economic evaluations were not necessarily relevant in assessing waste management options and waste disposal costs should be a significant term in the cost evaluation equation if waste minimization is not incorporated in the design.
- To minimize or eliminate waste streams would, in many cases, require modifications to the production process from which the streams emanated. This would require process and equipment R&D and costly irradiation requalification of the reactor fuel and target materials.
- Schedules could be jeopardized with the implementation of optimized waste minimization options for the FTFF.
- Design of some features of the facility could not be completed because process effluent processes and waste treatment options have not been identified.
- Design of the plant becomes more sensitive because of changes promulgated by federal, state and local environmental agencies. While such changes may reduce emissions of certain categories of chemicals, they may require modification to the basic processes and support equipment.
- Plant capital costs would probably increase but there appears to be substantial operating material cost reductions by recycling of chemical effluent streams.

RECOMMENDATIONS

While we did not have the opportunity to complete the FTFF plant Title I design (75% complete) due to NPR

Program deferral, several good working guidelines did emerge which are generally applicable.

- Assess process effluent streams (quantity, composition and physical properties) in the R&D phase prior to finalizing process design with emphasis on source reduction for waste minimization.
- Select effluent processing options based on product quality and production throughput. Continual recycle of process effluent streams may cause impurities to build up to intolerable levels and adversely affect product quality.
- Initiate design interface controls early between the process, plant effluent control and waste management engineers and maintain these interfaces during the life of the project.
- Design the facility with sufficient flexibility to accommodate anticipated changes in waste minimization technology and regulatory requirement changes.

REFERENCES

1. U.S. Department of Energy, General Environment Protection Program, DOE Order 5400.1, Nov. 1988.
2. U.S. Department of Energy, Hazardous and Radioactive Mixed Waste Program, DOE Order 5400.3, Feb. 1989.
3. U.S. Department of Energy, Radioactive Waste Management, DOE Order 5820.2A, Sept. 1988.
4. U.S. Department of Energy, Office of New Production Reactors, Fuel and Target Fabrication Facility Requirements Document, FTF-RD-0001, March 1991.
5. U.S. Department of Energy, Model Waste Minimization and Pollution Prevention Awareness Plan, February 1992.
6. The Pollution Prevention Act of 1990, November 1990.