Production Equipment Development Needs for a 700 Metric Ton/Year Light Water Reactor Mixed Oxide Fuel Manufacturing Plant

by
D.E. Blahnik

September, 1977

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PRODUCTION EQUIPMENT DEVELOPMENT NEEDS
FOR A 700 METRIC TON/YEAR LIGHT WATER
REACTOR MIXED-OXIDE FUEL
MANUFACTURING PLANT

by
D. E. Blahnik

September, 1977

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SUMMARY

We conducted a literature search and survey of fuel suppliers to determine how much development of production equipment is needed for a 700 metric tons/yr light water reactor (LWR) mixed-oxide uranium dioxide-plutonium dioxide (UO_2 - PuO_2) fuel fabrication plant. This work was performed for the Savannah River Laboratory. Savannah River Laboratory is developing a conceptual design and a design criteria for a plant in this size range for the Department of Energy.

The results of the study indicate that moderate to major production equipment development is needed in the powder and pellet processing areas. The equipment in the rod and assembly processing areas need only minor development effort. A summary is provided in Figure 1 of equipment development requirements.

Required equipment development for a 700 MT/yr plant is not anticipated to delay startup of the plant. The development, whether major or minor, can be done well within the time frame for licensing and construction of the plant as long as conventional production equipment is used.

FIGURE 1. MOX Fuel Fabrication Equipment Development Requirements Summary

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INTRODUCTION

Mixed-oxide (MOX) fuel production over the past 20 years has been limited to small-scale volumes. The majority of MOX fuel in the U.S. has been fabricated in laboratories and pilot plants using batch-type equipment and manual operations. The current annual production capacity of MOX fuel fabrication in the U.S. is estimated at 50 to 75 metric tons (MT). The largest plant in the world is probably the Belgonucleaire Plant, in Belgium, which can manufacture about 50 MT of MOX fuel per year. Therefore, a 700 MT/yr plant represents a substantial capacity scaleup over current plants.

This report summarizes the results from a study to evaluate the LWR MOX fabrication production equipment development needs. The evaluation is a result of a literature search and a general survey of nuclear fuel fabricators. We assumed that the equipment would be used in a hypothetical plant designed to manufacture 700 MT MOX fuel per year and would be capable of producing both pressurized water reactor (PWR) and boiling water reactor (BWR) fuels. We also assumed a MOX fuel fabrication process and determined which types of equipment and operations are preferred for a large plant before evaluating the state-of-the-art of the equipment. This was necessary since most of the past experience has been in small plants with batch-type equipment and manual handling.

The production equipment of concern in this study are both the process and materials handling equipment. The process equipment would include the major equipment items (e.g., powder blender, pellet sintering furnace, end cap welder, etc.) but not the ancillary items (e.g., gas supply, exhaust system, shielding, etc.). The materials handling equipment would include the in-line conveyors, index and feed mechanisms, storage bins, etc., that are used to move and store the fuel materials in the process.

CONCLUSIONS AND RECOMMENDATIONS

The results of this study indicate that moderate to major development is needed in the following areas:

- Process Equipment. Except for the rod load and decontamination steps the functional aspects of the equipment are fairly well developed through the entire process. However, substantial improvements are needed for equipment maintenance, cleanup, and replacement in the powder and pellet processing areas.
- Materials Handling Equipment. Substantial development is needed in the powder and pellet fabrication areas. It is important that mechanical transfer to and from equipment be done with a minimum of dust generation and pellet damage. Minimizing the spread of PuO_2 and mixed oxide dust within the containment areas will be important to maintain strict accountability and minimal radiation levels.

The literature search and survey indicate that at the front end of the process (powder receiving through blending) process equipment should be batch type with semi-mechanized operations. Continuous process equipment with fully mechanized operations are preferred from powder milling through pellet drying. Batch and/or continuous equipment with semi-mechanized operations are recommended for pellet inspection, rod fabrication, assembly fabrication and packaging. Table 1 shows a breakdown of the equipment evaluation.

Comprehensive industrial engineering studies should be made to assure that each piece of production equipment is sized properly and interfaces with adjoining production equipment, auxiliary equipment, gloveboxes, and other production lines in a systematic manner. The study reveals the difficulty of divorcing the evaluation of the process and materials handling equipment design from the rest of the plant facilities. An evaluation must consider plant operations as a whole: plutonium containment, criticality safety, shielding; waste, scrap, reject and rework streams; heating and ventilating, access control; accountability; etc.

TABLE 1. MOX Fuel Fabrication Equipment Evaluation Summary

EQUIPMENT OPERATING MODE PREFERENCE		EQUIPMENT "STATE-OF-ART" OPINION (a)													
(b) TYPES OF PROCESS EQUIPMENT		(c) REMOTE/NESS OF OPERATIONS		(d) PROCESS EQUIPMENT		(e) MAINTAINABILITY		(f) FUNCTIONABILITY		(g) CLEANUP AND REPLACEMENT		(h) MAINTAINABILITY		(i) CLEANUP AND REPLACEMENT	
												(j) MAINTAINABILITY	(k) CLEANUP AND REPLACEMENT	(l) MAINTAINABILITY	(m) CLEANUP AND REPLACEMENT
BATCH	OR BOTH OR CONTINUOUS	SEMI-MECHANIZED OR FULLY-MECHANIZED	2.5	2.5	3	2.5	2.5	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
BATCH		MANUAL OR SEMI-MECH	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BATCH		SEMI-MECHANIZED	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BATCH		SEMI-MECHANIZED	1.0	1.0	1.0	1.0	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOTH OK		SEMI-MECHANIZED	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOTH OK		SEMI-MECHANIZED	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
BOTH OK		SEMI-MECHANIZED	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CONTINUOUS		SEMI-MECHANIZED	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
X-RAY		SEMI-MECHANIZED	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
GAMMA SCAN		SEMI-MECHANIZED	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
VISUAL INSPECTION		SEMI-MECHANIZED	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
WEIGH		BOTH OK	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
CLEANUP		BOTH OK	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
AUTOCLAVE (IF DONE)		BATCH	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
ASSEMBLY		BATCH	1.5	1.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
FINAL INSPECTION		BATCH	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
WEIGH AND PACKAGE		BATCH	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

(a) EQUIPMENT "STATE-OF-ART" OPINION

(b) TYPES OF PROCESS EQUIPMENT - WOULD IT BE PREFERABLE TO USE A BATCH OR CONTINUOUS TYPE OF PROCESS? IT MAY BE DESIRABLE TO HAVE BOTH TYPES IN A PLANT.

(c) UNUSUAL FACTORY, NEEDS MAJOR REDESIGN AND DEVELOPMENT

(d) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(e) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(f) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(g) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(h) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(i) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(j) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(k) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(l) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(m) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(n) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(o) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(p) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(q) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(r) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(s) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(t) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(u) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(v) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(w) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(x) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(y) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

(z) SATISFACTORY, REQUIRES MINOR DESIGN AND DEVELOPMENT

Personnel with extensive experience in MOX fuel fabrication, large (≥ 700 MT/yr) UO_2 fuel plant operations, and other ceramic industry operations should participate in the design, development, shakedown and operation of the plant. The equipment supplier, architect-engineer and operating company should maintain close collaboration. It is important to maintain continuity of the management team through the design, development, construction, shakedown and long-term operating and maintenance improvement phases of the project.

Developmental activities on some of the equipment identified in this report should start at least 3 years before installation in the plant. It would be desirable to cold test an entire production line of equipment before it is installed. The large scaleup in this plant will probably result in a one- to three-year shakedown and production efficiency improvement phase after the equipment is installed. In the first year, standing materials, and then depleted UO_2 , should be processed for initial shakedown before beginning MOX production. The more advanced the testing of equipment and the training of maintenance personnel before plant startup, the more efficient the shakedown and operation of the plant will be.

This study is a general evaluation of development needs for equipment. We recommend the following for more detailed analysis of the equipment development requirements.

- Define in detail the process to be used.
- Specify the types of feed materials (e.g., 1st, 2nd, 3rd or GESMO generation Pu) and the batch sizes to be used.
- Determine the product mix to be manufactured by the plant (e.g., for BWR and/or PWR; 1st generation or 2nd generation reactors or Pu burners; enrichment, sizes, assembly mix) and volumes and schedules for each product.
- Determine if the full production capability must be installed at once or if it can be gradually built up.
- Define the regulatory criteria, especially the safeguards and shielding requirements, because they have a large impact upon the plant design. Criteria on effluents and waste are also important.

- The equipment and plant design team should:
 - 1) visit^(a) with current and past MOX fuel suppliers to determine if more detailed information on their equipment development experience and recommendations can be obtained, particularly in equipment areas identified to be lacking in this report
 - 2) solicit^(a) equipment manufacturers for their interest and information on equipment identified as needing the most development
 - 3) visit large (≥ 700 MT/yr) UO_2 plants.
- Conduct industrial engineering studies to determine the best types and layouts of equipment to be used in the plant to meet the product specifications and throughput requirements on a long-range basis.
- Establish the equipment criteria.

The production equipment can be improved fairly rapidly if the equipment is developed according to a well-defined plan. The materials handling equipment, in particular, might be developed rapidly because opportunity exists for using ingenuity with a wide variety of conventional materials handling and storage equipment already on the market.

(a) Workshops may be the most time cost-effective way for accomplishing this type of work.

STUDY DESCRIPTION

A literature search and general survey of nuclear fuel fabricators was made to determine the state-of-the-art of MOX fuel fabrication production equipment. The Bibliography lists the results of the literature survey. An effort to obtain more detailed information from fuel vendors was unsuccessful because they prefer to keep their process and equipment developmental work proprietary. We were also unable to visit fuel suppliers to obtain more detailed information and recommendations because of limited funding and lack of specific information about the product mix, feed materials, and process definition at the time of the survey.

LITERATURE SEARCH

An extensive literature search reveals very little public information on LWR facilities, and particularly LWR equipment. Most of the useful available information concerns liquid metal fast breeder reactor fuel facilities and fuel fabrication. The information available on equipment is primarily general and philosophical.

The most useful information on LWR fuel plants is in the GESMO⁽¹⁾ report and the Westinghouse Recycle Fuel Plant Docket.⁽²⁾ The Westinghouse Docket has by far the most detailed information about production equipment. The Docket was comprehensive and, thus, was selected to represent the GESMO Model Plant in many respects.

Over a decade ago MOX fuel processes were developed, and studies⁽³⁾ were made of facility designs, fuel fabrication costs, etc., for plants in the ton/day size range. General plant layouts and pictures of equipment appear in many of the references, especially the British reports. They have documented their experiences from start⁽⁴⁾ to finish^{(5)(a)} in their PFR fuel production campaign and have adopted a management approach that appears to work successfully for a MOX plant.

(a) Reference 5 should be required reading for MOX fuel plant designers.

EQUIPMENT DEVELOPMENT REQUIREMENTS

Equipment for a 700 MT/yr MOX fuel plant represents a scaleup of about 35 times the current largest plant in the U.S. and 14 times the world's largest plant. The state-of-the-art for a single-file production line size is about 50 MT/yr. The proposed Westinghouse plant for Anderson, South Carolina was sized with ~200 MT/yr line using branch parallel lines where throughput demands made it necessary.

Equipment was evaluated in terms of functionability, maintainability, and cleanup and replacement (Table 1). Safety is considered an integral part of these characteristics.

EQUIPMENT FUNCTIONABILITY

When the MOX fuel production equipment is evaluated for how well it will perform its functions, the following questions were considered:

- Has this equipment demonstrated adequate performance in processing a high volume of UO_2 fuels and/or pilot production runs of MOX fuels?
- Is the equipment highly reliable?
- Is the throughput capacity adequate for avoiding a large number of duplicate equipment items?
- Is the equipment adaptable to criticality safeguard requirements?

Process Equipment Functionability

The process equipment in the process assumed for this study is fairly well developed, primarily because of its use in UO_2 fuel plants. Those steps in the process identified as needing the most improvement in this category are:

- receiving and storage system for PuO_2 powder
- blending of mixed oxide powder
- quality assurance inspection and analysis of sintered pellets
- rod loading and decontamination.

Materials Handling Equipment Functionability

Substantial developmental work will be needed to improve the materials handling and storage function throughout the powder and pellet processing steps. Shielding requirements have necessitated minor equipment development for semi-remote handling of rods and assemblies.

The powder area requires conveyor and storage systems that provide containment of MOX dust for accountability, process control, and minimization of radiation levels. The pickup of extraneous contaminants and potential for reducing powder homogeneity (after blending) must be avoided. It is important that loading and unloading of materials at each process equipment piece be accomplished with minimal dusting and pellet damage.

EQUIPMENT MAINTAINABILITY

When the MOX fuel production equipment is evaluated for ease of maintenance, the following questions were considered:

- Is the equipment designed with emphasis on preventive and minimal routine maintenance, rather than unscheduled maintenance?
- Are components accessible for easy and rapid changeout (substitution)?
- Can procedures be implemented to minimize radiation exposures to maintenance personnel?
- Is the use of organic materials in the equipment minimized?

Process Equipment Maintainability

Existing process equipment needs substantial maintenance improvements in the areas of powder and pellet processing. Those steps in greatest need of improvement are receiving PuO_2 , milling, preslugging, granulating, continuous sintering and pellet inspection.

Materials Handling Equipment Maintainability

Materials handling between all process steps prior to pellet grinding requires major design and development attention. Handling between pellet grinding and rod end cap welding requires moderate improvements. Maintenance of rod and assembly handling equipment should be relatively simple if rods and assemblies can be removed from the equipment when internal maintenance is required.

EQUIPMENT CLEANUP AND REPLACEMENT

When the equipment is evaluated for ease of cleanup, modification or replacement, the following questions were considered:

- Is the equipment readily adaptable for use in glovebox and/or remote operations?
- Can the equipment be controlled to minimize the introduction of undesirable impurities into the fuel?
- Can the equipment be kept clean to minimize personnel radiation exposure?
- Can the equipment be easily decontaminated, removed from the facility and replaced?
- Are major components modular for ease of replacement?
- What about ultimate disposal of discarded equipment and volume reduction of such waste?

Process Equipment Cleanup and Replacement

This category is very important because it may be the greatest single source of downtime over the history of an operating plant. Equipment improvements are needed to assure easier cleanup and replacement through the entire powder and pellet areas. Rod and assembly areas appear adequate. Equipment must have a minimum of cracks, voids, etc., in those areas where powder can accumulate and where it is hard to remove. Rapid removal and replacement require quick disconnects, modular components, procedures, etc., which preclude the spread of contamination and minimize radiation exposure to personnel.

Materials Handling Equipment Cleanup and Replacement

Design and development improvements are most needed in the powder processing area and slightly less in the pellet process area. Rod and assembly handling equipment are not likely to become contaminated, but they must be kept clean to maintain fuel assembly cleanliness requirements.

Criteria which apply to process equipment cleanup and replacement also apply to the materials handling equipment.

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APPENDIX A

QUESTIONNAIRE FOR
FUEL SUPPLIER SURVEY

FORM A

GENERAL OPINIONS

1. In general, the process and materials handling equipment suitable for use in a high volume (~ 700 MT/yr) LWR mixed-oxide fuel manufacturing plant:
- a. Is already well developed ☐
 - b. Needs minor additional development ☐
 - c. Needs major additional development ☐
2. The following process and materials handling equipment items need the most development effort (Category Type 1.c above): _____
- _____
- _____
- _____
3. What approach should be taken to the design and development of Category 1.c equipment?
	<u>Yes</u>	<u>No</u>
a. Design and develop new equipment	☐	☐
b. Retrofit and adapt existing equipment used in UO_2 plants and other industries	☐	☐
c. Other _____		
- _____
4. Equipment manufacturers are interested in providing special mixed-oxide fuel production equipment:
	<u>Yes</u>	<u>No</u>
a. If an adequate market is established	☐	☐
b. If additional design and development is paid for by the customer	☐	☐

GENERAL OPINIONS (cont'd)

Yes

No

c. We plan to utilize our own designs

☐☐

d. Other _____

5. The general design philosophy on equipment used in mixed-oxide fuel plants:

a. For PuO_2 powder it should be: _____

b. For UO_2 - PuO_2 powder it should be: _____

c. For UO_2 - PuO_2 pellets it should be: _____

d. For fuel rods it should be: _____

e. For fuel assemblies it should be: _____

6. General comments are: _____

7. Qualifying statements on input are: _____

(PLEASE ADD SHEETS IF ADDITIONAL WRITING SPACE IS NEEDED)

FORM B

EQUIPMENT "STATE-OF-ART" OPINION*

ASSUMED PROCESS STEP	PROCESS EQUIPMENT			MATERIALS HANDLING EQUIPMENT (TRANSFER TO NEXT PROCESS STEP)		
	FUNCTION- ABILITY	MAINTAIN- ABILITY	CLEANUP & REPLACEMENT	FUNCTION- ABILITY	MAINTAIN- ABILITY	CLEANUP & REPLACEMENT
RECEIVING PuO ₂						
RECEIVING UO ₂						
BLENDING POWDERS						
MILLING						
PRESLUG PRESS						
GRANULATE						
SIZE CLASSIFY						
PELLET PRESS						
SINTER						
GRIND OD						
DRY						
DIM. CHECK & MOIST. ANAL.						
ROD LOAD & DECON.						
WELD CAP						
PRESSURIZE & SEAL WELD (IF DONE)						
LEAK TEST						
X-RAY						
GAMMA SCAN						
VISUAL INSP.						
WEIGH						
CLEAN						
AUTOCLAVE (IF DONE)						
ASSEMBLY						
FINAL INSP.						
WEIGH & PKG.						

*RATING CATEGORY

S = SATISFACTORY, OK AS IS, MAY REQUIRE MINOR DESIGN AND DEVELOPMENT

U = UNSATISFACTORY, NEEDS MAJOR REDESIGN AND DEVELOPMENT

FORM C
OPINION ON TYPES OF EQUIPMENT AND REMOTENESS OF
OPERATIONS THAT SHOULD BE USED
(PLACE "X" IN MOST PREFERABLE MODES)

ASSUMED PROCESS STEP	TYPES OF PROCESS EQUIPMENT			REMOTENESS OF OPERATIONS		
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