MASTER

MATERIAL CONTROL IN NUCLEAR
FUEL FABRICATION FACILITIES.^{1#}
ADDENDUM TO PART I:
FUEL DESCRIPTIONS AND
FABRICATION PROCESSES
(SAI REPORT NO. SAI-79-788-WA)

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1. INTRODUCTION

This addendum to SAI-79-788-WA, Part I: Fuel Descriptions and Fabrication Processes, contains some material which became available after the report was submitted to Lawrence Livermore Laboratory and some modifications to the report. The material will be incorporated into the final report, which will include all the results obtained in the three phases of the project. The addendum contains additional information on existing and planned nuclear fuel fabrication facilities in the world, and descriptions of a selected number of facilities including a conceptual facility which replaces the one initially presented and has been used as a basis for the discussions of material accountability and control.

2. FUEL FABRICATION FACILITIES IN THE UNITED STATES AND CANADA

The information base contained in Table 1 of Reference 1 has been expanded to include data on fuel fabrication facilities in the United States and Canada.

In addition to extracting data from the published literature, we have contacted seven fuel manufacturers in the United States and two in Canada, requesting general information on their fabrication activities. We were thus able to obtain valuable information, for which we wish to thank the following individuals:

B.D. Bushell, Canadian General Electric Co., Ltd., Canada
R.H. Ihde, The Babcock and Wilcox Co., United States
J.H. Krepick, General Electric Company, United States
R. Seif, Westinghouse Electric Corporation, United States
R.F. von Hollen, Combustion Engineering, Inc., United States
S. Williams, Nuclear Fuel Services, Inc., United States

The information obtained has been factored in Table 2.1, which contains data on eighteen existing and planned facilities. Not all entries are available for all the facilities listed.

TABLE 2.1
FUEL FABRICATION FACILITIES IN THE USA AND CANADA

Country	Location	Operator	Ownership	Type of Facility	Type of Fuel Produced	Yearly Capacity (MT)			Comments
						Uranium Fuel	Plutonium Fuel		
							Thermal Recycle	Fast Breeder	
USA	Parks Township, PA	Babcock & Wilcox	B&W	Pilot	MOX			2	Produces fuel pins for FFTF
	Lynchburg, VA	Babcock & Wilcox	B&W	Commercial	LWR	✓			Produces pellets, rods and assemblies. AUC conversion line will be installed
	Apollo, PA	Babcock & Wilcox	B&W	Commercial	UO ₂	✓			Conversion facility. Produces UO ₂ powder.
	Windsor, CT	Combustion Engineering	CE	Commercial	PWR	✓			Produces rods and assemblies
	Hematite, MO	Combustion Engineering	CE	Commercial	PWR	200			Produces UO ₂ power and pellets
	Cheawick, PA	Westinghouse	W	Pilot	MOX			✓	
	Columbia, SC	Westinghouse	W	Commercial	PWR	700			
	Anderson, SC	Westinghouse	W	Commercial (planned)	MOX		200		Conceptual design only
	Vallecitos, CA	General Electric	GE	Pilot	MOX			✓	
	Wilmington, NC	General Electric	GE	Commercial	BWR	✓			

TABLE 2.1

FUEL FABRICATION FACILITIES IN THE USA AND CANADA (Continued)

Country	Location	Operator	Ownership	Type of Facility	Type of Fuel Produced	Yearly Capacity (MT)			Comments
						Uranium Fuel	Plutonium Fuel		
							Thermal Recycle	Breeder	
USA	Richland, WA	Exxon Nuclear	Exxon	Commercial	LWR	✓			
	San Diego, CA	General Atomic	Gulf Oil, Royal Dutch Shell	Pilot	HTGR	3*			
	Youngsville, NC	General Atomic	Gulf, KDS	Commercial (planned)	HTGR	15*			Conceptual Design Only
	Canoga Park, CA	Atomics International	Rockwell International	Pilot	ATR	0.25*			Produces fuel for Advanced Test Reactor
	Erwin, TN	Nuclear Fuel Services	Getty Oil	Pilot	Pu,HEU	✓	✓		Has diversified capabilities for custom fuel elements
	Cimarron, OK	Kerr-McGee	KMG	Commercial	UO ₂				
CANADA	Toronto	Canadian General Electric	GE	Commercial	CANDU				Pellet Fabrication
	Peterborough Ontario	Canadian General Electric	GE	Commercial	CANDU	✓			Bundles fabrication

* U-235 (93% enrichment)

3. DESCRIPTION OF FUEL FABRICATION FACILITIES

3.1 Description of the Proposed HTGR Fabrication Facility

A large fabrication facility for HTGR fuel had been planned by General Atomic Co. at the Youngsville site in North Carolina. The project has been temporarily shelved, following the company decision to stop commercial HTGR offerings. The planned manufacturing facilities at Youngsville would have been enclosed in three buildings totaling approximately 156,000 square feet of floor space. The process descriptions were shown in Reference 1.

A conceptual scheme of a facility capable of fabricating six large HTGR cores (1160 MWe) per year is shown in Figure 3.1. Only the fissile line, which is significant from the safeguards point of view, has been shown in detail, with the coated fertile particles entering the process at the rod press step. The system represented in Figure 3.1 is divided into three main areas as follows:

- The particle production area, at the top.
- The rod and assembly area, at the bottom.
- The scrap recovery area, in the middle.

There are three types of symbols in Figure 3.1: the rectangles represent individual pieces of equipment; the circles represent storages; and the diamonds represent quality control or safeguards release areas.

The characteristics of the equipment included in the conceptual facility are listed in Table 3.1.

3.2 Cadarache Fabrication Complex

The plutonium fuel fabrication complex at Cadarache has supplied all plutonium fuels for the French fast breeder program.

Figure 3.1 Conceptual Scheme of HTGR Fuel Fabrication Facility.

TABLE 3.1

EQUIPMENT CHARACTERISTICS FOR CONCEPTUAL HTGR FACILITY

EQUIPMENT	NUMBER OF UNITS	CAPACITY PER UNIT	PROCESS CYCLE TIME (hours)
UF ₆ Reactor	1	6.4 Kg U	3.0
U ₃ O ₈ Dissolver	2	9.6 Kg U	8.0
Resin Contactor	3	3.2 Kg U	3.0
Dryer/Devolatilizer	4	3.2 Kg U	4.5
Converter/Buffer Coater	4	3.2 Kg U	3.8
SiC Coater	4	3.2 Kg U	4.1
Outer Low Temperature Isotopic Coater	2	3.2 Kg U	1.6
Particle Washer	2	3.2 Kg U	3.0
Compositor	2	51.2 Kg U	8.0
Meter/Blend	2	3200 Rods	1.0
Rod Press	2	3200 Rods	1.0
Assembler	2	1 Block	0.5
Cure-in-Place Furnace	2	22 Blocks	11.0
Block Cleaner	2	6 Blocks	3.0
Rod Dissolver	2	900 Rods	3.0
Static Burner	1	19.2 Kg U	20.0
Fluid Bed Burner	2	3.2 Kg U	4.0
Solvent Extraction	1	80.0 Kg U	24.0

The complex, in operation since 1962, includes two main buildings: the Plutonium Technology Workshop and the Chemical Purification Laboratory. A unit was designed within the existing buildings to provide the first core and next reloads for the Super-Phenix reactor (see Figure 3.2). Specific equipment capacities for this unit are contained in Table 3.2. (The process line details were shown in Reference 1.)

The unit is designed to supply 18 tons of Super-Phenix fuel (see Reference 1 for description of fuel) per year. To meet this demand a work shift of 8 hours per day 5 days a week would be required for all operations except for pellet sintering, which works on 2 12-hour shifts per day 5 days a week.

The total surface area required for the Super-Phenix unit is approximately 3,500 m². This figure does not include non-specific areas such as the Chemical Purification Laboratory and destructive testing areas of the Plutonium Technology Workshop. Approximate areas for specific process steps are:

- storage of raw oxides - 650 m²
- storage, checking, and preparation of nonactive components - 600 m²
- manufacturing pellets, statistical checking, and dry recycling of rejects - 650 m²
- manufacturing pins and uncladding rejected pins - 600 m²
- checking pins, winding spiral wire, setting the bundles, setting, checking and storing assemblies, packaging, and dispatching - 1,000 m²

The last area mentioned above refers to a part of the plant that is shared with other fabrications (Phenix, irradiations in Phenix, and fuel for light-water reactors). (2,3)

3.3 Description of the FFTF Fabrication Facility

The Babcock and Wilcox Company have fabricated more than two core loadings of FFTF driver fuel at the Parks Township plant in Western Pennsylvania since 1972. The plutonium fuel fabrication plant presently has the capability of producing and certifying 1,000 FFTF fuel pins per month. The facility consists of approximately 5,600 ft² powder and pellet fabrication area, 4,400 ft²

Assigned Areas of the Cadarache Fabrication Facility

Pellet fabrication
Rod fabrication
Rod inspection
Fabrication, inspection,
and storage of fuel
assemblies

Pellet Fabrication Layout

Figure 3.2 Assembly Plan of Super-Phenix Fabrication.

TABLE 2.2

EQUIPMENT CAPACITIES FOR CADARACHE FABRICATION UNIT

Pellet Fabrication Plant

- (a) a calcinating furnace
maximum temperature, 900°C
rate: 2 kg PuO₂/h
- (b) two ballmills with metallic natural-uranium balls capacity: 40 kg of oxide per batch
- (c) rotary homogenizer
capacity: 160 kg of mixed oxide
- (d) granulation unit
rate: 40 kg/h
- (e) three mechanical presses with hydraulic cushion rate of each press: from 8 to 30 strokes/min
- (f) sintering furnace under argon-hydrogen
rate: 10 kg of pellets/h.
- (g) dry grinding unit
rate: depending on the thickness to remove, average rate: 5 kg of pellets/h
- (h) dry recycling unit
rate: 3 kg/h

Pin Fabrication Plant

- (a) three cladding lines
rate of each line: 20 pins/h
- (b) wire winding unit
rate: 50 pin/h

Assembly Fabrication Plant
(rate: two assemblies/day)

- (a) pin bundle setting unit
- (b) device for introducing the bundle into the hexagonal tube
- (c) assembly setting unit (foot and upper neutron shielding welding).

assembly and inspection area, plus support areas for conversion, scrap recovery, and laboratories. (4,5)

The plutonium plant (see Figure 3.3) is comprised of nine distinct fabrication areas and the various necessary support areas. (6) Fabrication Area 1 (FAB 1) is used for FFTF fuel fabrication, while the other fabrication areas are presently or were once used for different fabrication processes. Fabrication process equipment (see Reference 1 for detailed process description) from powder receiving through pin loading as performed in Fabrication Area 1 are shown in Figure 3.4. However, recent improvements have slightly altered the process steps as described in Reference 1 and modified the layout presented in Figure 3.4. (6)

Removal of halogen impurities from PuO_2 requires calcining, ballmilling, and screening prior to mixed oxide blending. Present operations do not require these steps due to improved calcining prior to receipt of the PuO_2 at Babcock and Wilcox. The jetmill operation has been improved such that throughput rates greater than 5 kilograms per hour are maintained during that operation and screening after jetmilling is now optional. The addition of organic material is now done in a Turbula blender rather than a V-blender. The Turbula blender provides an excellent mixture of the heterogeneous materials. To eliminate the need to chemically process a sludge, the final improvement was to abandon wet grinding in favor of dry grinding. Dry grinding eliminates the need to wash and dry pellets as is necessary for pellets that are wet ground. The above changes are marked by an asterisk next to appropriate equipment named in the key to Figure 3.4.

3.4 Conceptual LWR Fabrication Process and Facility Descriptions

The conceptual LWR fuel fabrication process that has been chosen for this study is based upon the Westinghouse-Anderson design update which has been used in several safeguards analyses. (7-10) The primary modification in the process as presented here is that

Figure 3.3 Plutonium Plant Floor Plan and Area Designation

1. *Oxidation-reduction furnace
[eliminated due to improved
quality of PuO_2 receipts]	12. *Wash and dry pellets [eliminated due to use of dry grinder]
2. *Jetmill, screen and V-blend
[changed to improved jetmill,
optional screen, and Turbula
blend]	13. Pellet inspection
3. Slug (pre-press)	14. Pellet storage and off-gassing
4. Granulator	15. Furnace vacuum out-gassing
5. Classifier	16. Pellet stack make-up
6. V-Blend	17. Rod loading table
7. Hydromet press (pellet press)	18. Rod storage table
8. Inspection	19. Rod welding chamber
9. Pre-sinter furnace	20. Waste storage table
10. Continuous sintering furnace	21. Furnace vacuum drying
11. *Centerless grinder [changed
to dry grinding unit]	22. Furnace gas blender area
	23. Work bench area
	24. *Furnace area [eliminated
due to improved quality
of PuO_2 receipts]

*Recent changes to fabrication area, changes noted in brackets.

Figure 3.4 Fabrication Area 1 (FAB 1) Equipment Layout

the facility is assumed to receive MO_2 which contains 30 weight percent PuO_2 rather than pure PuO_2 . Thirty weight percent has been chosen as a representative value that has been discussed in the nuclear industry community for MO_2 coming out of a reprocessing-conversion facility. It allows the versatility to blend down slightly for recycled breeder fuels, or blend down to approximately 4 weight percent PuO_2 in MO_2 for recycled LWR fuels.

The following are criteria for the baseline MO_2 process.

- Annual operating capacity at 60% design capacity:
200 MT* MO_2 , 4 wt % PuO_2 , 96 wt % UO_2 ;
- Annual input: 843 pressurized MO_2 containers (32 kg each),
673 55-gal drums UO_2 (260 kg each);
- Annual output: 100,000 fuel rods (2.0 kg MO_2 each),
20 million pellets (10 g each);
- Customer target enrichment specifications: within
 $\pm 0.1\%$ (absolute);
- Shift structure: three shifts per day, 1000 shifts per
year, consisting of a 7-day cycle of 19 or 20 shifts
followed by one or two cleanout shifts;
- Batch structure: one 225-kg MO_2 sub-blend per produc-
tion shift, 1 blend = 21 sub-blends (assume one reject
sub-blend per blend);
- Scrap rates: 10% of throughput recycled as clean scrap;
less than 1% dirty scrap;
- Total number of personnel: ~400 individuals working in-
side the manufacturing area.

*Metric tonnes

Annual plutonium in the MO_2 feed for the conceptual plant is 8000 kg, or about two-thirds of the plutonium output of the proposed Allied-General Nuclear Services (AGNS) facility for reprocessing the spent fuel generated annually by fifty 1000-MWe LWR's.

The conceptual process is shown in Figure 3.5 and includes the feed, product, and clean scrap flows.

MO_2 is received in containers and stored. When removed from storage the containers are weighed, opened and randomly sampled for chemical analysis. The MO_2 powder is transferred pneumatically to one of three bulk storage vessels each having a capacity of 570 kg.

UO_2 is received and stored in a separate area. The UO_2 containers are then unloaded and transferred pneumatically to a bulk hopper.

A sub-blend of materials is made up from three different feed supplies: new MO_2 , UO_2 , and MO_2 recycled from the process stream. Each type of material is transferred from bulk storage to a feed hopper which then automatically meters out a programmed amount of material to a weigh hopper. Materials from the three weigh hoppers are then released to the blender. At the completion of the blending cycle, the sub-blend is transferred pneumatically through a reduction mill to one of the nine MO_2 storage silos reserved for a single sub-blend (225 kg MO_2).

The incoming feed for the powder granulation and pellet-pressing steps is a 225-kg sub-blend from one of the MO_2 silos. The material is compacted, granulated, and mixed with lubricant. The granulated particles are fed to the pellet press. The resulting green pellets are loaded into boats that sit on a conveyor. The green pellets are inspected for density, and rejects are returned to the clean scrap recovery system (CSRS). The conveyor transfers the boats to the sintering furnaces and acts as a buffer storage.

Figure 3.5 MO₂ Process Line (average flow per 8-h shift)

Boats of green pellets are selected from green-pellet storage and conveyed mechanically to the pellet sintering process. Five sintering furnaces operate in parallel. The density of selected pellets is determined, and any overfired pellets are returned to the CSRS. Underfired pellets are returned for more sintering. Boats of acceptable pellets are stored on the sintered-pellet conveyor pending their release to the pellet grinder.

Sintered pellets are then taken from the boats, their surfaces are grinded to a specified diameter, inspected for dimensions and nicks, and acceptable pellets are loaded into trays. Two independent process lines (one operational, one stand-by) are available. Grinder sludge, chips, and off-specification pellets generated in these processes are returned to the CSRS. Trays are mechanically conveyed to one of two buffer storage/dryer units and stored by a stacker-retriever system. Pellet samples are taken from the storage/dryer after 4 hours for moisture analysis.

In the next step, a tray of pellets is retrieved from storage, and a row of pellets is aligned with the open end of a rod and fed into the rod. This is repeated until the specified number of pellets has been inserted. Each rod receives an end spring and a top-end plug, and is then decontaminated and inspected. Rejection rods are unloaded and the pellets are returned to the main process stream or to the CSRS. Minor rod repairs are made.

Fuel rods are stored in channel carriers, which are placed in one of four shielded storage compartments by a stacker-retriever.

The CSRS conditions clean (high impurity) MO_2 scrap collected from pellet fabrication operations and from fuel rod repair and dismantling. Batches of 20-30 kg are reduced in size in a crusher and are subsequently processed by multiple oxidation-reduction steps. A batch is processed through one of two oxidation-reduction reactors. The forming gas used for reduction is non-explosive 6% H_2 -94% N_2 . The recovered MO_2 powder is transferred to recycle storage.

The analytical services facility (ASF) is a conventional analytical chemistry laboratory in which small samples from the main process stream are analyzed. Criticality control zones maintained within the ASF have a plutonium limit of 290 g. All samples are transferred pneumatically from the source to the central material handling station (CMHS) of the ASF, where they are logged in, split, and distributed for different types of analysis. The estimated weekly load is 200-300 samples. Of every 100 grams of mixed oxides handled by the laboratory 60 grams is returned to MO_2 blending, 20 grams is shipped to miscellaneous waste treatment as dirty scrap, and 20 grams is treated as liquid waste.

Facility layouts are shown in Figures 3.6, 3.7, and 3.8, and a listing of types of equipment, number of units and capacities are presented in Table 3.3.

Figure 3.6 Facility Layout of MO_2 Fuel Plant⁽⁸⁾

Figure 3.7 Second Floor Level of MO₂ Fuel Plant⁽⁸⁾

Figure 3.8 First Floor Level of MO₂ Fuel Plant⁽⁸⁾

TABLE 3.3

CAPACITIES OF CONTAINERS AND STORAGES
FOR THE MIXED-OXIDE FACILITY

Unit Process	Description	Number of Units	Unit Capacity
1A,2A	MO ₂ shipping container	--	32 kg MO ₂
2A	MO ₂ storage vault	1	134 MO ₂ shipping containers
3A	MO ₂ can (4 per shipping container)		8 kg MO ₂
4A	MO ₂ blending and bulk storage	10	570 kg MO ₂ (1 blend)
1B,2B	55-gal drum UO ₂	--	250 kg UO ₂
2B	UO ₂ storage vault	1	90 drums
4B	UO ₂ bulk storage	1	3000 kg UO ₂
4C	MO ₂ recycle storage	3	720 kg MO ₂
5	MO ₂ feed hopper	3	~30 kg MO ₂
5	MO ₂ weigh hopper	3	~30 kg MO ₂
5	Recycled MO ₂ feed hopper	1	~50 kg MO ₂
5	Recycled MO ₂ weigh hopper	1	~40 kg MO ₂
5	UO ₂ feed hopper	1	~230 kg UO ₂
5	UO ₂ weigh hopper	1	~200 kg UO ₂
6	MO ₂ blender	1	~280 kg MO ₂
6	MO ₂ storage silo	9	225 kg MO ₂
7	Compactor feed hopper	2	~20 kg MO ₂
7	Pellet press feed hopper	2	~50 kg MO ₂
7,8,9, 10,11	Pellet boat (5 in. x 12 in. x 12 in.)	--	1500 pellets, 15 kg MO ₂
8	Green-pellet belt conveyor storage	1	58 boats
10	Sintered-pellet storage (buffer)	1	135 boats
11,12	Pellet tray	--	900 pellets, 9 kg MO ₂
12	Sintered-pellet tray storage (buffer)	2	444 trays
13,14 15,16	Fuel rod	--	200 pellets, 2 kg MO ₂
15	Fuel rod storage channel	--	50 rods, 100 kg MO ₂
15	Fuel rod storage	1	25,000 rods
15,16	Shipping box	--	200 rods, 400 kg MO ₂

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