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Preliminary Conceptual Design and Cost Analysis of the DUPIC Fuel Fabrication Plant

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Abstracts

A preliminary conceptual design of the DUPIC fuel fabrication plant with production capacity of 400 MTHE/yr is presented. Capital and operating costs are also included. The levelized unit fabrication cost (LUC) for a reference mode was estimated at $509/kgHE, and sensitivity of some variable parameters to this reference was analysed.

Introduction

Since early nineties, the DUPIC(Direct Use of spent PWR fuel In CANDU) fuel cycle has been studied as the third alternative to the conventional options in Korea. The basic concept of the DUPIC is to reuse spent PWR fuel directly in CANDU without involving any separation of sensitive material.

This paper represents the preliminary conceptual design and the cost estimation of the DUPIC fuel fabrication plant to refabricate spent PWR fuels of 400 MTHE/yr into CANDU fuels. A set of technical requirements based on the results of basic research programs conducted for past few years, and the functional and material flow diagram of the reference fuel fabrication process were developed as the design basis. According to the design basis, the configuration of building facilities was developed, including process system arrangement, hot cell layout, and interface requirements of both unit processes. From such design features, the capital and the operating costs were estimated. Some of unit costs of the system components or the operation activities were referred from the AIROX studies by Rockwell International[1] and Idaho National Engineering Lab.[2], and the other available literatures[3,4]. Sensitivity analysis to the reference cost was also conducted by varying the production capacity, the rate of discount, and the contingency. The cost data derived from this study will be useful for the economic analysis of the DUPIC fuel cycle.

Design Basis

Major assumptions established as a design basis for the DUPIC fuel fabrication plant are :

1. *Reference precess :* OREOX(Oxidation REduction of OXide fuel) process for the powder processing for spent PWR fuel material and the CANDU fuel fabrication process, of which all processes are remotely operated in hot cell.

2. *Reference material to be processes :*

   - Feed : Spent PWR fuel assembly(initial enrichment : 3.5 wt.% of U-235, discharge burnup : 35,000 MWD/MTHE, decay time : 10 years, uranim weight per assembly : 440 kg)
   - Product : DUPIC fuel bundle of which mechanical design is the same with that of CANFLEX

3. *Plant production capacity :* Spent PWR fuels of 400 MTHE are annually fabricated into CANDU fuels with loss rate of 1%.

4. *Plant availability* : 70 % (equivalent 255 full operating calendar days per year : The 70% availability requirement for the DUPIC fuel fabrication facility covers allowances for normal process systems startup and shutdown times, scheduled and unscheduled plant equipment maintenance and repair activities, material accountability related tasks that affect plant operation, and any scheduled plant-wide outage period for major systems refurbishing activities.

5. *Scope of plant* : The DUPIC fuel fabrication plant is a complete fuel recycle plant that covers all functions and equipments for processing the spent PWR fuel and converting it to the DUPIC fuel. The non-fuel components required by the fuel design(CANFLEX) such as fuel cladding, end caps, end plates, and dysposium fuel rods are supplied from off-site facility in ready-to-use conditions.

6. *Environmental and safety standards* : The DUPIC fuel fabrication plant is designed and operated in accordance with the US environment, safety regulatory and licensing requirements.

Process Description

Fig.1 shows a schematic diagram of the DUPIC fuel fabrication process and material balance. The substantial fabrication processes are :

- *Spent PWR fuel receiving and storage* : The as-received spent fuel is classified by the information(e.g. fissile content) characterized and evaluated by the fuel design data and the burnup characteristics, and stored in the classified sections.

- *Disassembly and decladding* : The spent PWR fuel rods are removed from the spent fuel structure. The fuel structural hardware is compacted for volume reduction and packaging for off-site disposal. The cladding of the fuel rod is punctured in a controlled environment such that fission gases are collected for waste treatment. The cladding of the fuel rod is sliced logitudinally with laser cutter and spent fuel pellet are removed from the cladding. The cladding hulls are also compacted with density of approximately 4.7g/cm^3 and packaged as a solid waste.

- *Fuel oxidation and reduction* : The spent fuel pellet fragments and its debris go through three oxidation and reduction processing cycles to get a powder form with suitable characteristics for fuel fabrication. Three conduction ovens are used for each batch of fuel material : the first is used in the oxidation step ($UO_2 \rightarrow U_3O_8$ at ~400°C, diluted oxygen), the second is used for flushing out the reaction gas in the fuel material(at ~500°C, argon), and the third is used in the reduction step ($U_3O_8 \rightarrow UO_2$ at ~600°C, hydrogen/argon). These three ovens are arranged in series and equipped with specially designed automatic material transfer mechanism. The resulting fuel powder is mixed, sampled for size distribution, and assayed for fissile content. The acceptable powder material is temporarily stored in batch quantities for fuel pelletization. During these processes, volatile and semi-volatile fission products, and particulates are trapped by an appropriate filter system.

- Fuel Pelletization : Before the powder material is formed into pellets, the powder material is pre-compacted and granulated to increase its flowability. A lubricant is added to the powder to facilitate the pelletization process and improve the press tooling life. The powder material is then compacted to a desired green density. The resulting pellets are stacked onto boats and conveyors for sintering. The sintering step is then conducted at a high temperature in reducing atmosphere to achieve the high pellet density required. After that, the sintered pellets are transferred to the pellet grinding station to achieve the final dimension and surface finish within specification tolerances. All defective pellets and scrap materials are forwarded to the scrap recycle station. The finished pellets are stacked in specially designed containers for fuel pin fabrication.

- *Fuel Pin Fabrication* : The fresh fuel cladding and end cap components processed at off-site are shipped to the DUPIC facility with one end cap already welded. The stacked fuel pellets are loaded into the fuel pins and moved to the end cap welding station. The welded fuel pins are non-destructively tested for weld quality including a helium leak testing. The defective fuel pins is transferred to the scrap material recycle station. The completed fuel pin is also assayed for fissile content and then transported to the fuel bundle assembly work area.

- *Fuel Bundle Assembly* : According to CANFLEX design, the DUPIC fuel bundle consists of two different diameter fuel pins. The center fuel pin (the larger size of the two pin diameters) contains a poison material (dysprosium) mixed with standard natural uranium fuel. The bundle assembly station receives the finished fuel pins from the respective fuel pin fabrication lines and assembles the fuel bundle. The assembled bundles are non-destructively tested for weld quality, dimensions fit, and clearance. Defective fuel bundles are forwarded to the repair station or scrap recycle station. The acceptable fuel bundles are loaded into baskets and storage containers for transfer to the storage or shipping area

Facility Description

- *Plant site and building layout* : The plant requires approximately 0.4 km^2 of dry and plot land. The main processing buildingis located at the center of the site. Other surface features for support systems are scattered around the main processing building with approximately 30m buffer zone. Dose rate at site boundary will be well below the regulatory limit of 5 mrem/yr.

- *Main processing building* : Figure 2 shows the main process building and process systems layout. The main process building is a 64m x 113m rectangular-shaped structure that is 23m high above the grade level of 30.5m with access from the three sides. The main entrance at south side leads to the main process control centers and operation-related offices. Receiving and shipping of the spent fuel material and the non-fuel material is available through the west side and the north side, respectively.

  In the the north side of the building, two straight, identically shaped process canyons are configured side-by-side with process monitoring through shielded viewing windows and remote operating galleries around the side walls of each canyon. Each canyon is 91.4m long and 9.1m wide with varied floor elevation and ceiling height. At the west end of each canyon, the floor is extended down to the 23m elevation to accommodate the space required for vertical disassemblying and decladding system. The rest part of the floor for 55m of the canyon length is at the grade level with high ceiling section of 50.3m elevation. This high ceiling space is to accommodate the fuel process equipments for the two different size pellets and pins fabrication. At the below grade level of 23m, hot maintenance, repair and decontamination cells are located. The other utilities, support systems, and gaseous waste treatment systems are located above the oxidation/reduction process at the 43m elevation. The canyon wall, ceiling, and floors are lined with 6.4mm stainless steel liners to facilitate decontamination activities.

- *Process systems and equipments* : As shown in Fig. 2, there are two fuel fabrication process lines in one canyon. Each process line contains process systems starting from the disassembly system to the final assembly of the DUPIC fuel bundle.

  The as-received spent PWR fuels are inspected and stored in the storage vault. A number of selected spent fuels for an appropriate batch are picked up and transported to the west end of the process cell. The spent PWR fuel is processed in each process line as explained in the process description. The new DUPIC fuel bundles from four process lines are transported to the inspection and packaging area located at the south-east end of the building. The loaded fuel basket is transported to the new DUPIC fuel storage vault located at the west end of the main process building.

Cost Estimation

Once a preliminary conceptual design of the DUPIC fuel fabrication plant was established, and the cost estimate was prepared from the available vendors' quotes on the standard equipment and referred from the estimates of similar type/size of systems/equipments for similar types of the DUPIC facility. In many cases, the estimates used in the 1992 AIROX studies[1, 2] were served as the basis for this estimation. In other cases of non-standard items that had never been designed or applied, engineering judgements were made by the degree of system reliability and expert's consultation. Typical construction costs were determined using the construction industry standards[5, 6].

Table 1 shows the estimated capital and operating costs, and the levelized unit fabrication cost(LUC) for a reference model. The date of the cost estimates was the end of 1995. The total capital cost was estimated at approximately $918M including direct and indirect costs. The direct costs include the costs for site preparation, process system/equipment, main process building , support facilities, etc., and for the indirect cost the costs for design&engineering, licensing, taxes, etc. and contingency were included. Annual operating cost was estimated at about $140M per year including the costs for staff, utilities, consumable materials, equipment replacement and waste disposal. The cost for decontamination and decommisioning assumed to be about 25% of capital cost was estimated at $210M. In order to determine the 40-years life cycle cost of the DUPIC fuel fabrication plant, the amount of current year funds that would be required to build, operate, and decommission the plant during the time frame of 2015 to 2059 was estimated to be about $1,083M using the discount rate of 5.0%. LUC was determined to be about $509/kgHE by deviding the total life cycle cost by the sum of the discounted annual production rate during the operation period of 2020 to 2059. As listed in table 1, LUC is governed by annual operation cost corresponding to about 301$/kgHE. Especially, the cost for process waste disposal was found to have strong effect on the operation cost.

Fig. 3 shows the sensitivity analysis of the production capacity, the contingency for capital cost estimate, and the discount rate to LUC of the reference model. As shown in this figure, LUC is decreasing as the production capacity increases, while LUC is increasing as the contingency and the discount rate are increasing. From the view point of economics of the plant, the production capacity appears to be one on the major parameters affecting on LUC.

Reference

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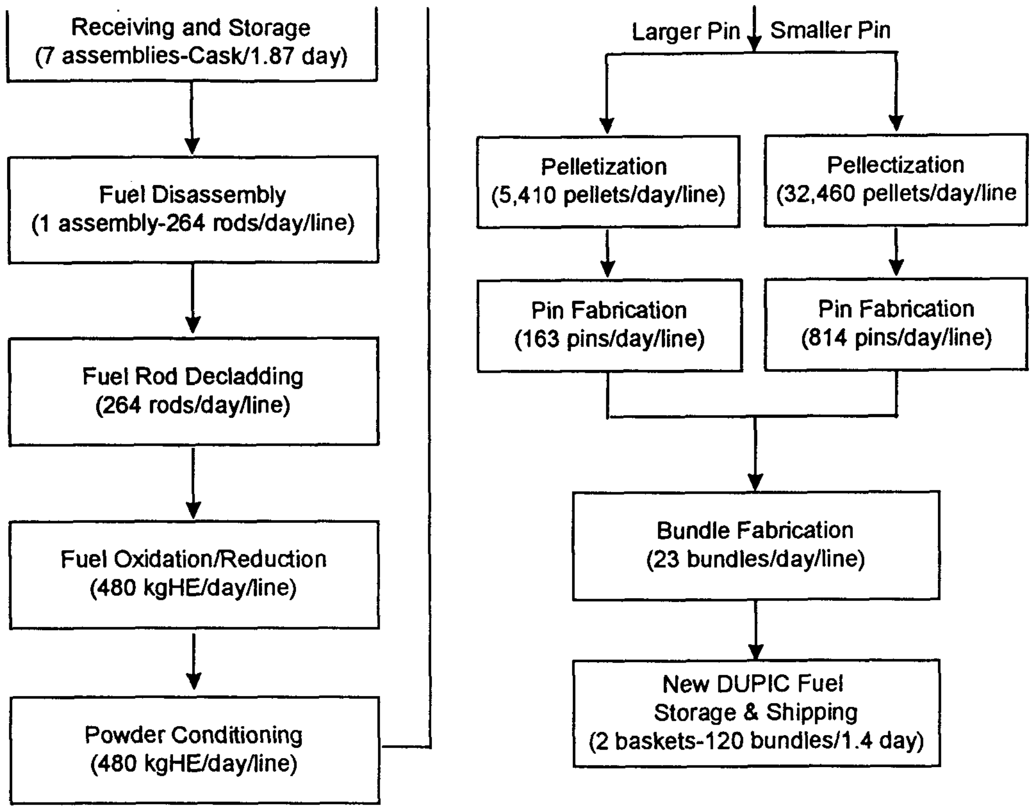

Figure 1 Schematic Diagram of the DUPIC Fuel Fabrication Process

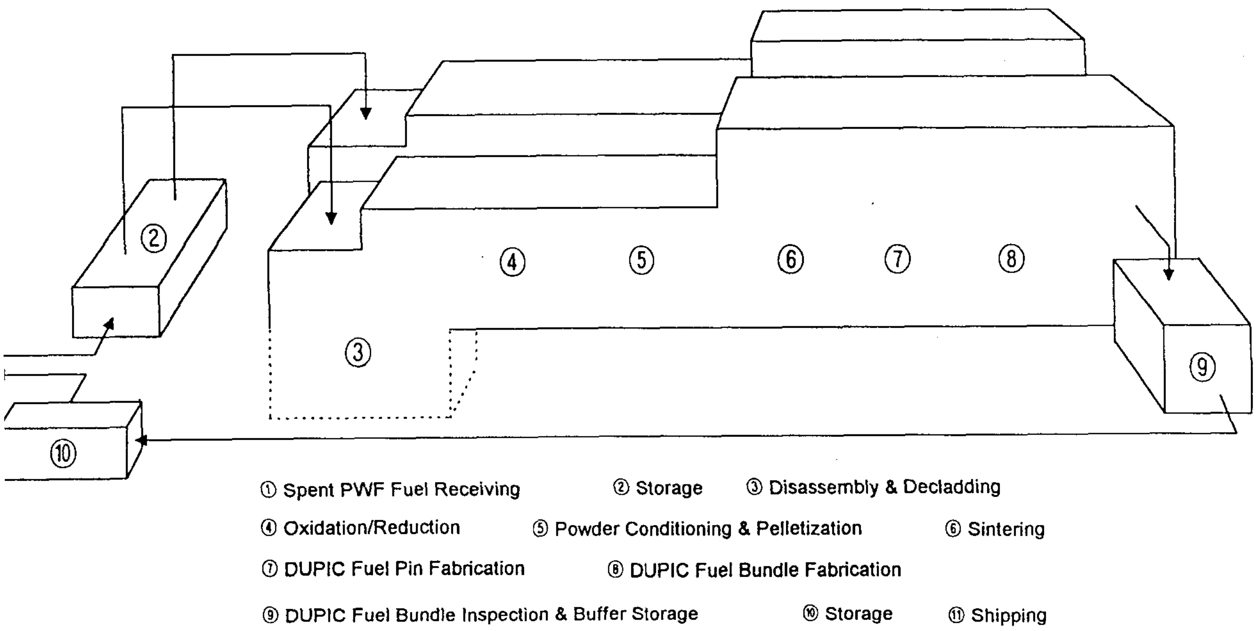

Figure 2 Hot Cell Structure of the DUPIC Fuel Fabrication Plant

Table.1 Estimated costs for the DUPIC fuel fabrication plant with 400 MTHE/yr

Item		Cost(M$)	LUC($/kgHE)	Remarks
Capatal Cost	Direct Cost[a]	420	*146*(29%)	
	Indirect Cost[b]	498		Contingency : 40% of the direct costs
Annual Operation Cost	Staff	22	*350*(69%)	
	Utilities	9		
	Materials	20		
	Equipment Replacement	21		~10% of equipment cost
	Process Waste Disposal[c]	68		
Decontamination&Decommisioning		210	*13*(2%)	
40-years Life Cycle Cost		1,083		
Levelized Unit Fabrication Cost($/kgHE)			***509***	

* Note ;

a) Direct cost includes site preparation, fuel fabrication system, main process building, support facilities(health physics, safeguards and security, fire protection, administration, warehouse), utilities, off-site facility, etc.

b) Indirect costs include the costs for design (14%), engineering&construction management(10%), licenses(20%), building permits(3%), taxes and insurance(2%), G&A(6%), startup&testing(20%), training(3%), etc. The value in parenthesis is a percentage of the total direct costs.

c) The process radioactive wastes include vitrified dirty scrap waste(1% of the production capacity) of 10 m^3, vitrified semi-volatile waste of 41 m^3, compacted fuel structural material of ~66 m^3, and miscellaneous waste of ~764 m^3.

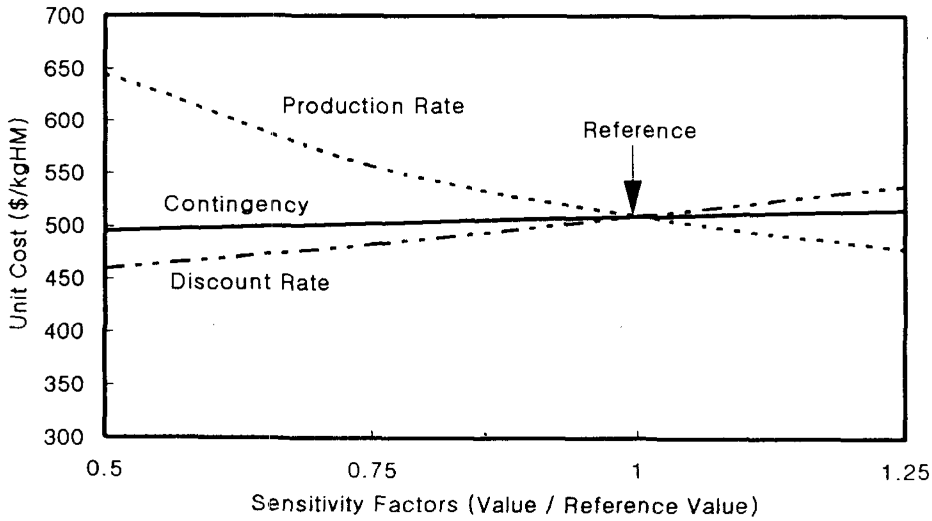

Figure.3 Sensitivity of Production capacity, Contingency and Discount Rate to the Levelized Unit Fabrication Cost