'97 Workshop on Spent Fuel Management Technology,
Nov. 13-14, KAERI, Taejon, Korea.

Conceptual Development of a Test Facility for Spent Fuel Management

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Abstract

Spent fuel management is an important issue for nuclear power program, requiring careful planning and implementation. With the wait-and-see policy on spent fuel management in Korea, research efforts are directed at KAERI to develop advanced technologies for safer and more efficient management of the accumulating spent fuels. In support of these research perspectives, a test facility of pilot scale is being developed with provisions for integral demonstration of a multitude of technical functions required for spent fuel management.

The facility, baptized SMART(Spent fuel MAnagement technology Research and Test facility), is to be capable of handling full size assembly of spent PWR fuel(as well as CANDU fuel)with a maximum capacity of 10 MTU/y(about 24 assemblies of PWR type). Major functions of the facility are consolidation of spent PWR fuel assembly into a half-volume package and optionally transformation of the fuel rod into a fuel of CANDU type(called DUPIC). Objectives of these functions are to demonstrate volume reduction of spent fuel(for either longer-term dry storage or direct disposal) in the former case and direct refabrication of the spent PWR fuel into CANDU-type DUPIC fuel for reuse in CANDU reactors in the latter case, respectively. In addition to these major functions, there are other associated technologies to be demonstrated : such as waste treatment, remote maintenance, safeguards, etc.

As the facility is to demonstrate not only the functional processes but also the safety and efficiency of the test operations, engineering criteria equivalent to industrial standards are incorporated in the design concept. The hot cell structure enclosing the radioactive materials is configured in such way to maximize space utilization and ergonometrics, but to minimize costs within the given functional and operational requirements.

1. Introduction

The SMART facility consists of hot cell complex, service systems and others.

The core of the SMART facility is the shielded enclosure(hot cell) system in which major functional processes are accommodated. Other cells for subsidiary works, associated with the main operations, such as waste conditioning, remote maintenance, are arranged in this complex. This hot cell complex is a shielded concrete structure with adequate space and configuration with remote systems for in-cell operations and maintenance. The hot cell complex is configured to optimize functional design requirements, with due respect to safety requirements, in such way to minimize hot cell space and to facilitate remote maintenance. Supplementary to the remote D&M(decontamination and maintenance), the contact maintenance system, which would not require extensive shielding, covers the tail-end maintenance function.

The service systems constitute the periphery around the hot cell complex or outside boundaries. Various systems of equipment and instruments are installed around the hot cell complex for service operation, safety monitoring and control.

- The waste management system is an important part of the service system. There are several categories of wastes that arise from hot cell complex operation.
  - Process wastes are collected in the hot cell into a buffer storage area, which is in fact shielded cell(s).
  - Operational wastes are stored in a separate area with less extensive shielding.

  All the wastes will be eventually transported to the Central Radwaste Treatment Facility(RWTF) at KAERI for their treatment, and long-term storage. But adequate waste treatment systems will be provided in the SMART facility to meet the acceptance criteria of the RWTF.

- The personnel service area, including health physics services, shower rooms, and locker change rooms, provides service space for control of personnel flow in and out of work areas.

- The utility area accommodates conventional utility services, and the warehouse area provides inventory services for various materials, equipment, components, and parts.

- The analytical laboratory area includes shielded analytical lines and glove boxes to provide and ensure material accountability and process quality control.

The rest of the facility consists of non-radioactive area separative from the hot cell complex and service systems.

- The mockup test area is essentially a cold equipment operational checkout and training area for in-cell equipment systems.

- The guardhouse, administrations offices, conference room, library, and control rooms are also included in this area.

1) Functions

- Major functions of the facility will include:
  - Reception and handling of spent fuel transportation cask,
  - Unloading, inspection, and lag storage of spent fuel assembly,
  - Spent fuel rod consolidation(tilt down, clamping, top or bottom nozzle removal, and rod extraction),
  - Spent fuel rod collection and packaging in canister,
  - Fuel skeleton cutting, compaction and packaging in canister,
  - DUPIC(Direct Use of spent PWR fuel In CANDU) fuel fabrication(fuel rod cutting, decladding, powder preparation, pelletization, sintering, DUPIC fuel pin and bundle fabrication, inspection and quality control)
  - Consolidated fuel canister and DUPIC fuel bundle package inspection and lag storage,
  - Loading of sealed packages into ship-out cask, and
  - Ship-out cask handling and shipping.

- In addition to these major operations, some support functions of the facility are also included in the scope:
  - Development of safeguarding technologies for spent fuel,
  - Accounting and analysis of nuclear materials,
  - Test of remote operation, decontamination, and maintenance,
  - Radioactive waste treatment and storage,
  - Additional buffer storage of spent fuel or waste packages, and
  - Other associated functions to support the facility operations.

In order to implement this functional scope, adequate ancillary functions and support facilities will be provided in the design.

2) Capacity Bases

The facility is to be capable of handling full size power reactor fuel element of PWR and CANDU type. As the facility is to be used for research and developmental purposes and not for production, capacity figures are not especially significant. The capacity will be a function of the complexity of the process and the design of the process equipment.

The design throughput of the facility shall be;

- 10 MTU(24 assemblies) of spent PWR fuel per year for rod consolidation
- 10 MTU of spent PWR fuel per year for DUPIC fuel fabrication

3) Facility Availability and Facility Design Life

The facility shall be sized and operated based on the following assumptions for design in consideration of the scale and operational mode of the facility;

- 8 hours working in a day
- 5 days working in a week
- 150 days working in a year

The design life of the facility shall be 40 years.

2. System Design Concept

1) Site

The site for this facility will require a minimum of 33,000 m^2 [150 m(W) x 220 m(L)] of dry, flat land with solid soil or rock geological formations in the foundation. The site plan includes the SMART building, fire pump house, reserved spent fuel cask storage area for future use, parking lots, guard house, road and fence, etc. The overall site plan for this facility is shown in Figure 1.

2) Building Design

The facility building is a rectangular structure with dimensions of 58.5 m wide, 60 m long and 23 m high. It has eight floors including two basements. The elevation of the first floor is at the reference ground level of 0.3 m. The second basement floor is 8.5 m below the first floor; The first basement floor, 4.0 m below the first floor; the second floor, 4 m above the first floor; and the third floor, 8 m above the first floor; the fourth floor, 11.5 m above the first floor; the fifth floor, 16 m above the first floor; the sixth floor, 20 m above the first floor. The top of the roof for the facility is 23.0 m above the first floor slab and the other roofs have elevations below that roof.

The floor space of the facility building is about 15,000 m^2. The functional areas of each floor are shown in Table 1 and the general finish schedule is summarized in Table 2. The plan and section drawings of the building, including hot cell complex are given in Figures 2 and 3.

The building is a reinforced concrete structure and is composed of the hot cell structure and hot cell peripheral structure. The hot cell structure is made of heavy concrete and normal concrete. The main structural frame is basically a concrete box system. The building houses the different equipment, systems and facilities necessary to operate the SMART facility.

Personnel access to the building is through the lobby at the south side of the building. Radioactive materials are moved in and out of the building through the truck bay in the rear(north) side of the building.

The building is designed to meet the seismic criteria prescribed in the general requirements of the SMART facility.

3) Material Handling Scheme

Material Handling is an important consideration for safe and effective operation and maintenance of the SMART facility. They include such major operations as the transfer and handling of cask, spent fuel assembly, fuel rods, DUPIC fuel, canisters, in-cell HEPA filter, waste and in-cell equipment.

A truck with a cask arriving at the facility is checked at the guard house before entering the facility. The truck is washed out in the truck washing area, and it is moved to the truck bay, where the protective cover and the cask are removed from the vehicle by a 50/10 ton overhead crane.

If the cask is contaminated, it is decontaminated in the cask decontamination area by spraying demineralized water under high pressure. The cask is subsequently lowered through the hatch onto the cask transfer cart in the cask preparation area for unloading. Preparations for unloading include gas cooling and sampling, removal of cask outer lid, removing/loosening of bolts on the cask inner lid, and installation of special adapter onto the cask. The cask is then moved into cask unloading vestibule, where final preparations are made for unloading spent fuel into the consolidation cell.

In the hot cell complex, the spent fuel assembly is disassembled in the consolidation cell and rods are directed either to packaging cell or to DUPIC fuel fabrication cell. Spent fuel rods and DUPIC fuel bundles from the hot cell line operations are finally transferred to the packaging cell waiting for shipping. In the cask loading cell, the canisters are washed out and loaded into the cask thus completing hot cell operation. The loaded cask is then transferred to the truck bay, where the cask is loaded onto a truck for transport to its destination.

Wastes arising from the hot cell processes are collected by suitable methods and sent to the waste compaction room for further treatment. Spent in-cell HEPA and fines collection filters are also forwarded to and compacted in the waste compaction room. The compacted filters are loaded into drums, which are loaded into a cask and transferred off-site.

The schematic functional flow for this facility is shown in Fig. 4.

4) Hot Cell Complex

In the SMART facility, the hot cell line provides the primary containment and shielding for all major operations involved in the nuclear material flow. The core of the hot cell line is the consolidation cell and DUPIC cells that encompass all the major equipment for processes of radioactive material. A small annex cell at the end of consolidation cell, fuel rod integrity test(IT) cell, accommodates some test equipment to perform nondestructive test for fuel rod.

The DUPIC fuel fabrication cell line occupies the east wing of the L-shape hot cell complex to enclose a series of process equipment systems as required for DUPIC fuel fabrication and associated functions, in optimal configuration. The DUPIC wing of the hot cell complex has a U-shape in terms of DUPIC material flow from spent PWR fuel to DUPIC fuel bundle product. The layout of the DUPIC fuel fabrication cell complex is arranged in such way to avoid or minimize cross contamination between the DUPIC cells and with neighboring cells (rod consolidation and packaging) and to facilitate remote operation and maintenance, as well as in consideration of optimizing overall facility layout.

The decontamination and maintenance(D&M) cell supports the operations of these cells, and provides capability to perform routine maintenance and repair of the handling and process equipment. The waste compaction(WC) room accommodates equipment to reduce the volume of spent HEPA filters, contaminated structural parts, fuel skeletons and failed equipment for subsequent transfer. The waste packaging cell provides the capability to collect high and intermediate level solid wastes and package for subsequent handling. The waste storage room accommodates equipment for collection and store of high and intermediate level liquid waste.

The rework shop provides the capability to perform remote repair work on failed equipment. The suspect repair(SR) room provides the capability for contact maintenance of equipment that is contaminated with low level of the radioactivity.

All of the cells have floors and walls lined with stainless steel for ease of decontamination. The specification of these hot cells is summarized in Table 3.

5) Safety Features

SMART facility, having various functions as described above and being an one-of-a-kind facility, calls for establishment of safety requirement and/or goal from conception phase. Philosophy of safety goal governing the whole design work is set up based on, among others, the following rationales;

- Although the SMART facility is conceived not for production but for research purposes, the levels of safety against radiation should be comparable with those of commercially operating nuclear facilities.

- Conceptual design should take conservative criteria for safety into consideration, which will meet licensing and public acceptance requirements that would become severer in the foreseeable future than today.

The SMART facility uses multiple zone concepts for both radiation protection and contamination control. The facility has 4 radiation zones which ensure enough safety margin for radiation dose limit. Confinement zones consist of physical barriers and HVAC systems, isolating 4 areas with regard to potential degree of contamination. The HVAC system provides control and maintains respective zone differential pressures that will ensure airflow from the less contaminated zones into the contaminated zones. Filtration systems are provided with as many HEPA filter layers as applicable to ensure HVAC exhaust to the environment meet Korean rules together with ALARA requirements in order to protect the public, plant personnel, and the environment.

Efforts are also extended to meet the stringent criticality safety requirements. The subcriticality requirement during hot cell operation was so established that the effective multiplication factor, keff, is maintained below 0.95 under any design event conditions. By design, no liquid/moderator is present in the hot cells during normal operation. The lag storage pits are designed with curbs to provide additional protection against the entry of decontamination solution. For additional assurance, the quantity of decontamination liquid per batch is limited so that, if the liquid were present, the liquid level would be well below the safety height of the stored assemblies in lag storage. Furthermore, by design, an operator will need to attach a removable spool piece in the decontamination liquid supply line in order to use the decontamination system. This is to ensure that no decontamination solution can be introduced into the hot cell without strict supervision.

The SMART facility design provides radiation protection by making use of engineered safety features, including radiation shielding. The gamma and neutron radiation shielding were analyzed by the QAD-CGGP and the ANISN-W, respectively, with simplified geometries and design conservatism.

3. Design Criteria

1) Spent Fuels

Two types of PWR fuel and one type of CANDU fuel, which are currently used in Korean nuclear power plants, are selected as the reference spent fuels for SMART facility design;

- Korean standard PWR fuel assembly (K-SFA, 16x16 type),
- Vantage 5H PWR fuel assembly (V5H, 17x17 type), and
- CANDU fuel bundle

2) Applicable Codes, Standards, and Regulations

Korean regulations to be applied to the design and licensing a research facility like the SMART facility have not yet been fully established. As many other foreign facilities with specific research purposes may do, the facility has some of its own functions that may not be covered by any regulations.

Applicable codes and standards or regulations may be selected from those that have been applied to similar("anchor") facilities in foreign countries. The areas for which Korean regulations exist, however, shall be governed by Korean regulations; e. g., radiation protection, transportation of waste, contamination control, and, by rules of the Korean Ministry of Science and Technology (hereinafter "MOST"), Korean Building Code and Korean Fire Protection rules.

Some areas of design and licensing may exist that are listed in the foreign codes and standards or regulations, but may not be appropriate for application to the facility. KAERI shall provide a list of those items required by reference regulations. The decisions on the range or depth of application of those items shall be made in next design stage.

Table 1. Functional Areas of Each Floor

Unit : m^2

Item	El -8.2 m	El -3.7 m	El 0.3 m	El 4.3 m	El 8.3 m	El 11.8 m	El 16.3 m	El 20.3 m	Total
Hot cell	449		721			512			1,682
Analytical lab. area			225						225
Operating galleries	711		1,135			729	850		3,425
Receiving/ shipping bay			250						250
Cask mainte. area			250						250
Aux. systems	1,736	1,570	100	88	88	749		1,510	5,841
Active lab.					225				225
Labs					65	427			492
Offices			519	428	531	165			1,643
Public area	60	42	310	313	233	237			1,195
Total	2,956	1,612	3,510	829	1,142	2,917	850	1,510	15,228

Table 2. General Interior Finish Schedule

Area	Substrate	Finish	Material	Remarks
Contaminated Area I(Vent. Zone IV)	Concrete	Floor	S.S. lining	Hot cell or high level radioactive area
		Wall	S.S. lining	
		Ceiling	S.S. lining	
Contaminated Area II(Vent. Zone II to III)	Concrete	Floor	Special coating, vinyl sheet	Contaminated area except contaminated area I
		Wall	Special coating	
		Ceiling	Special coating or suspended ceiling	
Non-contaminated Area (Vent. Zone I)	Concrete or concrete block	Floor	Vinyl tile, ceramic tile, stone, conventional coating	Office, conference room, corridor, lobby, locker room
		Wall	Ceramic tile, stone, conventional coating	
		Ceiling	Suspended ceiling (administration area), conventional coating(lab. area)	
Equip. Room	Concrete or concrete block	Floor	Special coating or vinyl sheet	Exhaust air room
		Wall	Acoustical panel	
		Ceiling	Acoustical panel	

Table 3. Summary of Hot Cell/Room Specification

Item		Dimension (L m x W m x H m)	Major Functions	Major Handling Equipment
EL +0.3 m	Consolidation cell	21 x 8 x 10 (β γ -tight)	o S/F assembly unloading o S/F assembly inspection o S/F disassembly o Fuel skeleton cutting o S/F assembly lag storage	o 5 ton O/H Crane o 3 ton robotic bridge transporter o Servo-manipulator o M/S manipulator
	Pellet fabrication cell	20 x 6 x 8 (α γ -tight)	o S/F rod cutting o S/F rod decladding o Powder preparation o Pelletization o Sintering	o 5 ton O/H Crane o Servo-manipulator o 1 ton robotic bridge transporter o M/S manipulator
	Fuel pin fabrication cell	9 x 6 x 8 (α γ -tight)	o DUPIC fuel pin fabrication o Inspection and Quality control	o 3 ton O/H Crane o Servo-manipulator o 1 ton robotic bridge transporter o M/S manipulator
	Fuel bundle assembly cell	6 x 6 x 8 (β γ -tight)	o DUPIC fuel bundle fabrication o Inspection and Quality control	o 3 ton O/H Crane o Servo-manipulator o 1 ton robotic bridge transporter o M/S manipulator
	Packaging cell	8 x 6 x 10 (β γ -tight)	o Consolidated fuel/ DUPIC fuel bundle packaging o canister lag storage (Consolidated fuel, DUPIC fuel) o Inspection and Quality control	o 3 ton O/H Crane o 3 ton robotic bridge transporter o Servo-manipulator o M/S manipulator
	Loading cell	6 x 3.5 x 10 (β γ -tight)	o Canister decontamination o Canister shipout	o M/S manipulator
	Integrity test cell	8 x 3 x 5 (β γ -tight)	o Fuel rod integrity test	o 1 ton O/H Crane o M/S manipulator
	Analytical lab.	12 x 3 x 3 (β γ -tight)	o Sample preparation o Destructive analysis	o 1 ton O/H Crane o M/S manipulator

Table 3. Summary of Hot Cell Specification(continued)

Item		Dimension (L m x W m x H m)	Major Functions	Major Handling Equipment
EL 11.8m	D&M cell	29 x 13 x 7/9 (β γ -tight)	o Equipment decontamination o Equipment- and crane-remote maintenance/repair	o 10 ton O/H Crane o Servo-manipulator o 3 ton robotic bridge transporter o M/S manipulator o Transport cart
	Intervention Area	13 x 11 x 7	o Equipment decontamination o Equipment-contact maintenance/repair	o 20 ton O/H Crane o Transport cart
EL -8.2m	Waste compaction Room	5 x 8 x 7 (β γ -tight)	o HEPA filter-, fuel skeleton-, solid waste-compaction o Contaminated solid waste compaction o Packaging & shipout	o 3 ton O/H Crane o E/M-manipulator o M/S manipulator o Transport cart
	Waste storage Room	3 x 10 x 7 (β γ -tight)	o Liquid HLW/ILW storage	o 3 ton O/H Crane o M/S manipulator o Transport cart
	Waste packaging room	4 x 8 x 7 (β γ -tight)	o Solid HLW/ILW storage o Packaging & shipout	o 3 ton O/H Crane o M/S manipulator o Transport cart
	Rework shop	4 x 8 x 7 (β γ -tight)	o Decontamination o Equipment repair (remote)	o 5 ton O/H Crane o Servo-manipulator o M/S manipulator o Transport cart

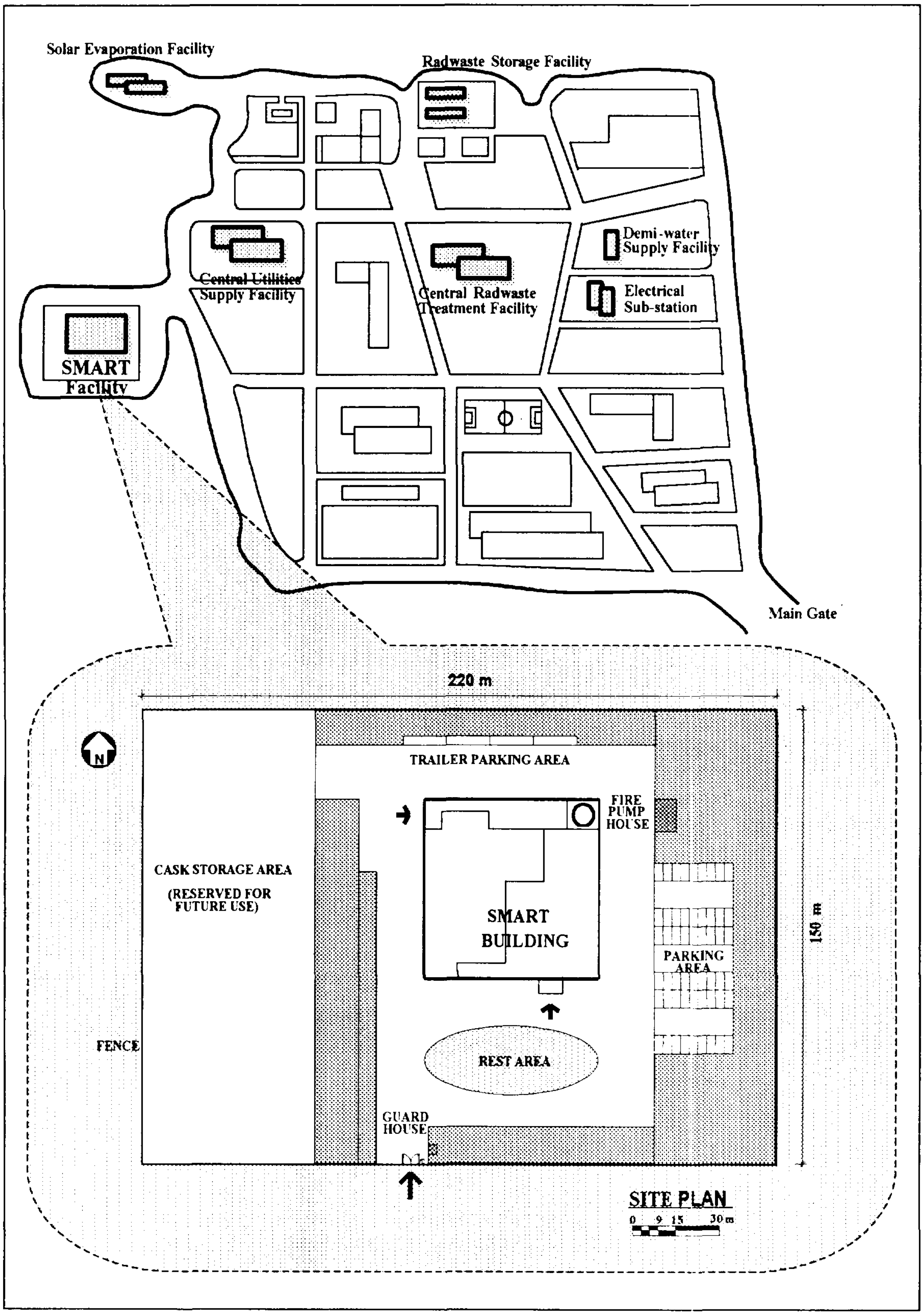
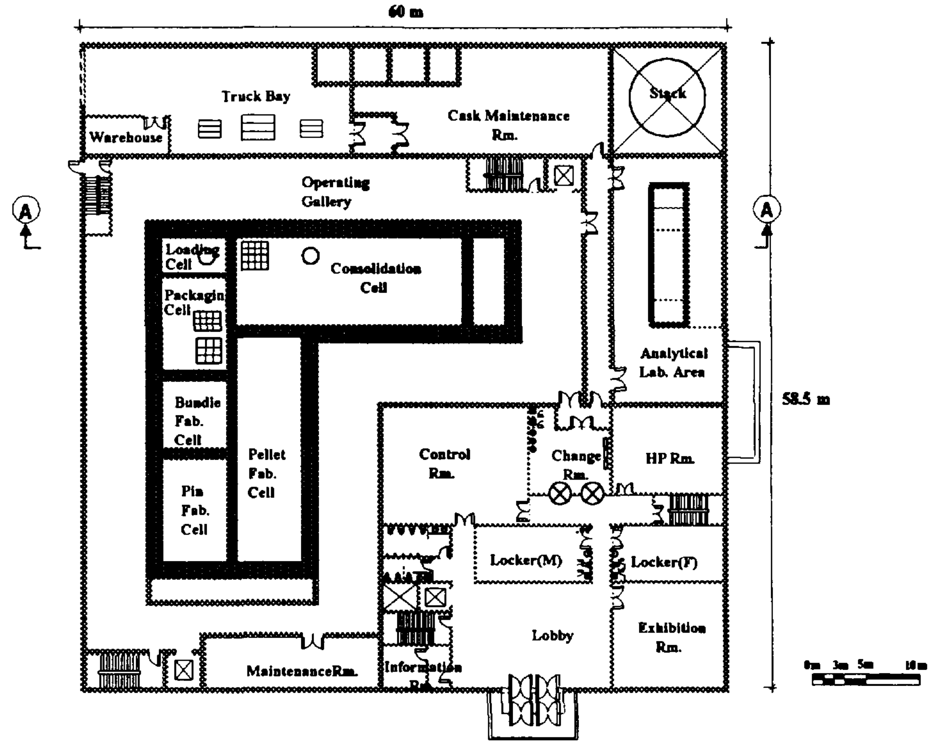
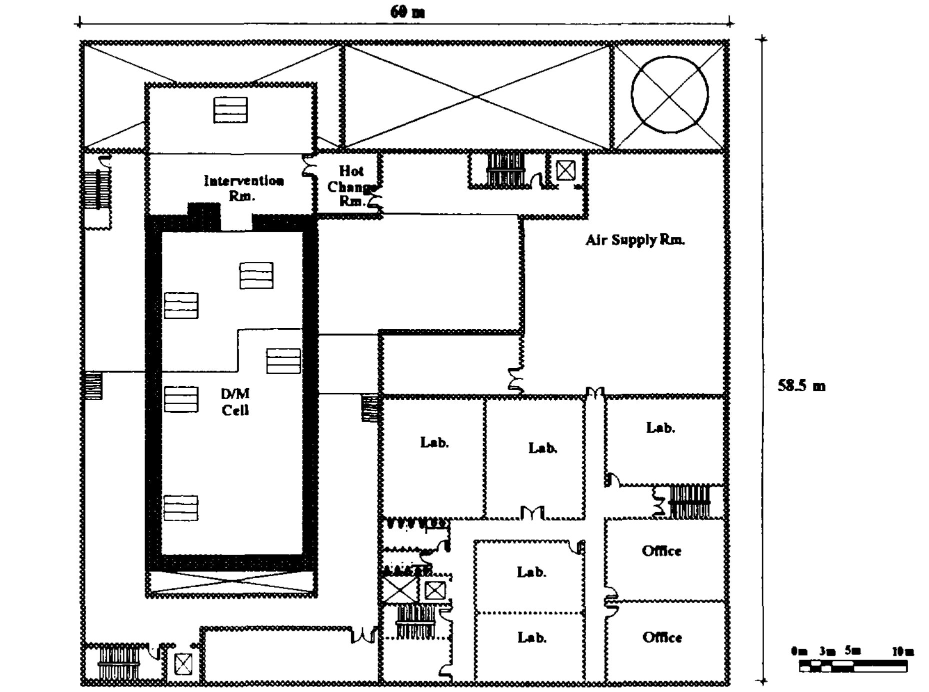


Fig. 1. Overall Site Plan for SMART Facility.



EL + 0.3 m



EL + 11.8 m

Fig. 2. Plan View.

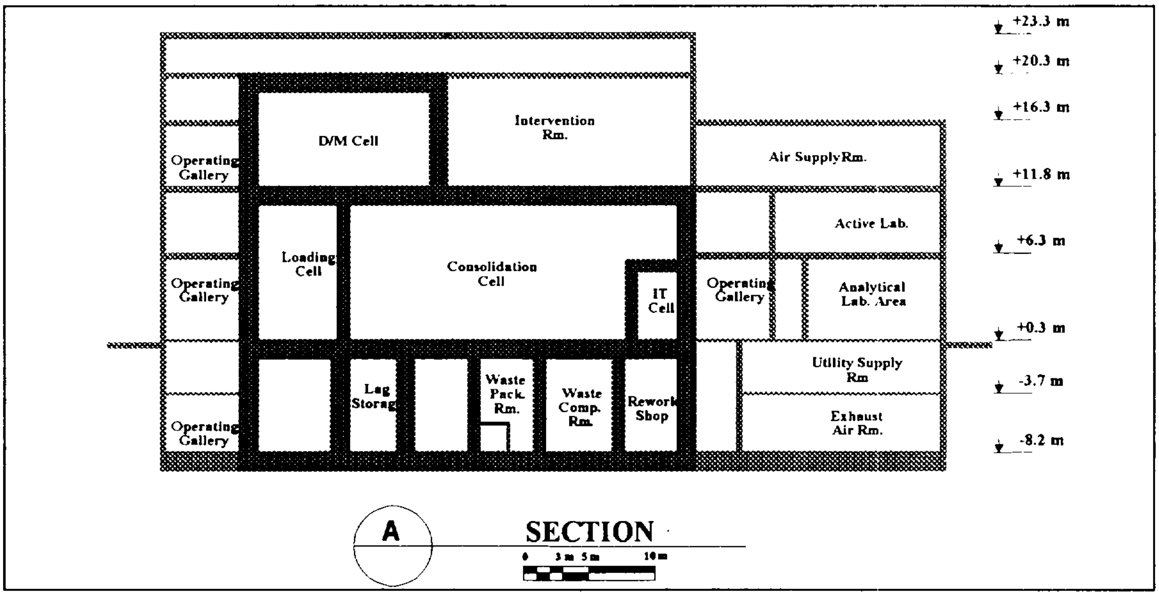


Fig. 3. Section A-A.

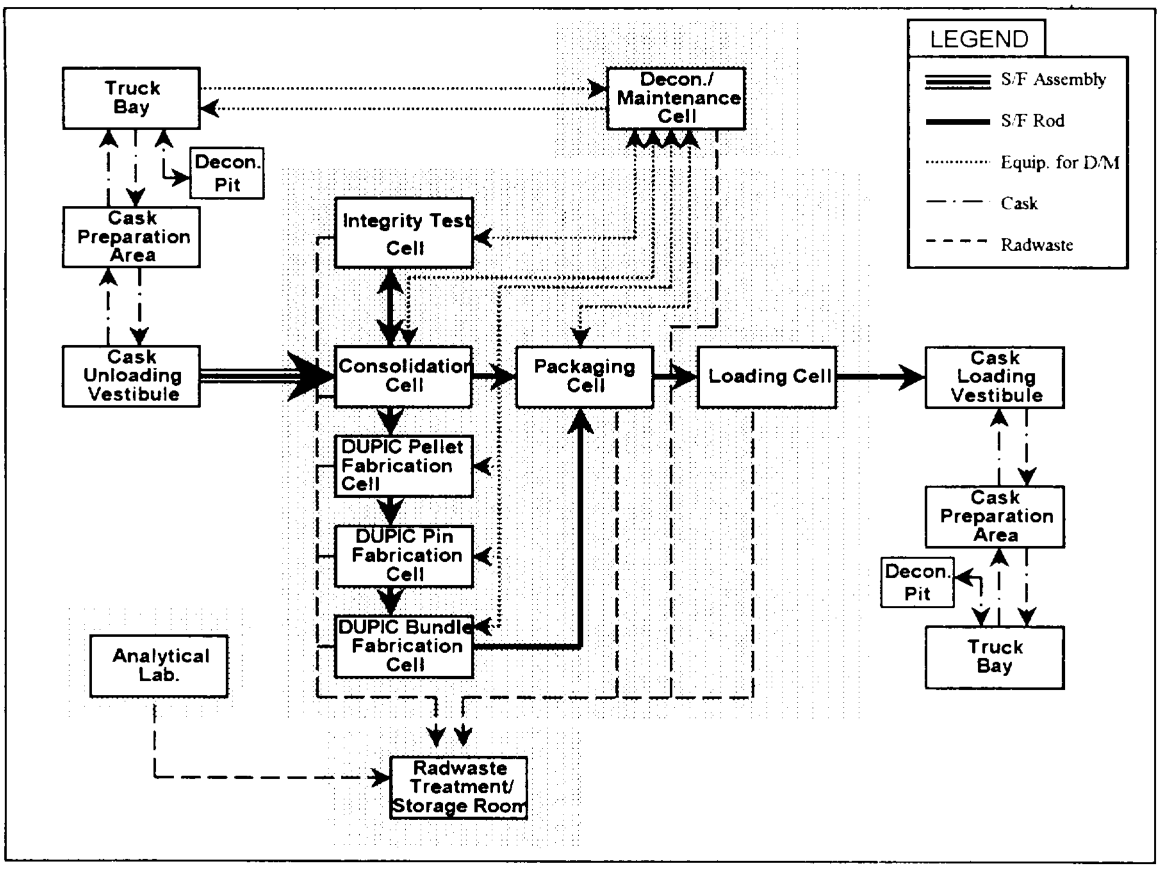


Fig. 4. Schematic Functional Flow Diagram of SMART Facility.