

THE USE OF PASSIVE, SECURE CELLS FOR PROCESSING OF HIGHLY ACTIVE NUCLEAR WASTES

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ABSTRACT

Passive, secure cells (PSCs) have been used for over 50 years at the Sellafield nuclear site in the UK for radioactive processing plants. PSCs are designed and constructed with the expectation that there will be no need to enter them throughout the life of the plant. EnergySolutions has full and exclusive rights in North America to use the intellectual property and knowhow generated at the Sellafield site and this includes all the design and operational data for PSCs. These data are thus available for use in the new build of nuclear plant currently being envisaged under the GNEP initiative.

There are three types of PSC. Type 1 PSCs contain plant items with no maintainable moving parts, and pipework is all welded and radiographed to nuclear standards. Type 2 PSCs contain plant items with slowly rotating or intermittently moveable parts, but all maintainable items such as motors and gearboxes are located outside the cell, with sealed through-cell-wall drives. Type 3 PSCs are a newer design, dating from the 1980s, in which all maintainable in-cell items are designed as removable modules. The housings for the equipment are permanently welded into the in-cell pipework, and the modules can be withdrawn from these housings, through removable hatches in the PSC roof, into shielded steel “flasks”. The flasks are moved to a maintenance cell where the modules are repaired or prepared for disposal. The process is reversed to re-install the modules back into service in the PSC.

All three types of PSC have been shown to have operability, maintainability, reliability, space utilization, contamination control and worker radiation dose uptake advantages over canyon-based plants. The increased capital cost of PSCs over canyons is offset by decreased operating costs. Although PSCs have lower flexibility for process change than do canyons, this can be mitigated by the provision of spare cells and pipework at the design stage. Entry to PSCs is possible but has been required only rarely at Sellafield. Design features of PSCs minimize the potential for internal contamination and therefore such entries are actually easier and subject workers to a lower dose-uptake than canyon entries.

INTRODUCTION

EnergySolutions has full and exclusive rights in North America to use the intellectual property and knowhow developed over 50 years at the Sellafield nuclear site in the United Kingdom. This site has operated three nuclear fuel recycling plants, three vitrification plants, dedicated equipment maintenance facilities, and a wide range of supporting nuclear waste treatment cleanup and storage plants over its lifetime. Some 2,000 million curies ($5.4E16$ Bq) of high level waste have been processed and over 70% of this waste has now been vitrified and is placed in engineered, passively-cooled stores at the site. More radioactivity has been vitrified at Sellafield than the total high level waste radioactivity held at the major US nuclear sites.

The design and operation of these nuclear processing plants has been expedited by the development and optimization of heavily shielded, passively safe, secure enclosures or “cells” to contain the processing equipment. This is in contrast to the “canyon” system developed in the USA, where complete plant items (tanks, valves, pumps etc) can be removed for maintenance or replacement by remotely disconnecting pipe “jumpers” that connect the equipment to the process pipework, and then lifting the plant item out using a remotely operated canyon crane. Passive, secure cells, (or “dark cells” as they have become colloquially but somewhat inaccurately known) on the other hand are constructed with no expectation of personnel entry or internal manipulation of equipment during the life of the plant. They therefore contain no moving mechanical equipment or instruments that would require maintenance during the plant life, or alternatively have such equipment contained in remotely removable modules. Passive secure cells (PSCs) make maximum use of maintenance-free all-welded stainless steel tanks and pipes, compressed air or steam driven liquid pumping

devices, and compressed air-based instruments. Other instruments such as thermocouples are introduced from the outside of the PSCs via guide tubes that are not open to the cell internal atmosphere. There are “through-wall” drives for certain rotating equipment and these locate the equipment requiring maintenance outside the cell. Shielded “bulges” in the cell roof and walls allow access to equipment that needs periodic manipulation such as sampling devices and valves for compressed air & steam supply. Certain items of in-cell equipment have internal modules that can be removed into shielded flasks for maintenance elsewhere in the plant. As well as obviating or simplifying maintenance, the sealed nature of the cells significantly enhances the security of the nuclear material contained within them.

This paper provides an overview of the nuclear processing plants at Sellafield, and describes the use of PSCs within them. It describes the design principles employed for these cells and shows how these have been realized in practice and how they have contributed to the successful operation of the plants. The application of these principles, and the lessons learned from operating the Sellafield plants, to the new nuclear plant build that is now being contemplated in the USA is discussed.

THE SELLAFIELD NUCLEAR PROCESSING SITE IN THE UK

The Sellafield nuclear site in the northwest of England, UK, is shown in Figure 1 and the features of some of the major processing plants on the site are summarized in Table I. The site was established in the early 1950s to produce nuclear weapons materials by irradiation of uranium metal nuclear fuels. This was done initially in simple air-cooled “Piles” with the fission heat being dissipated to atmosphere.

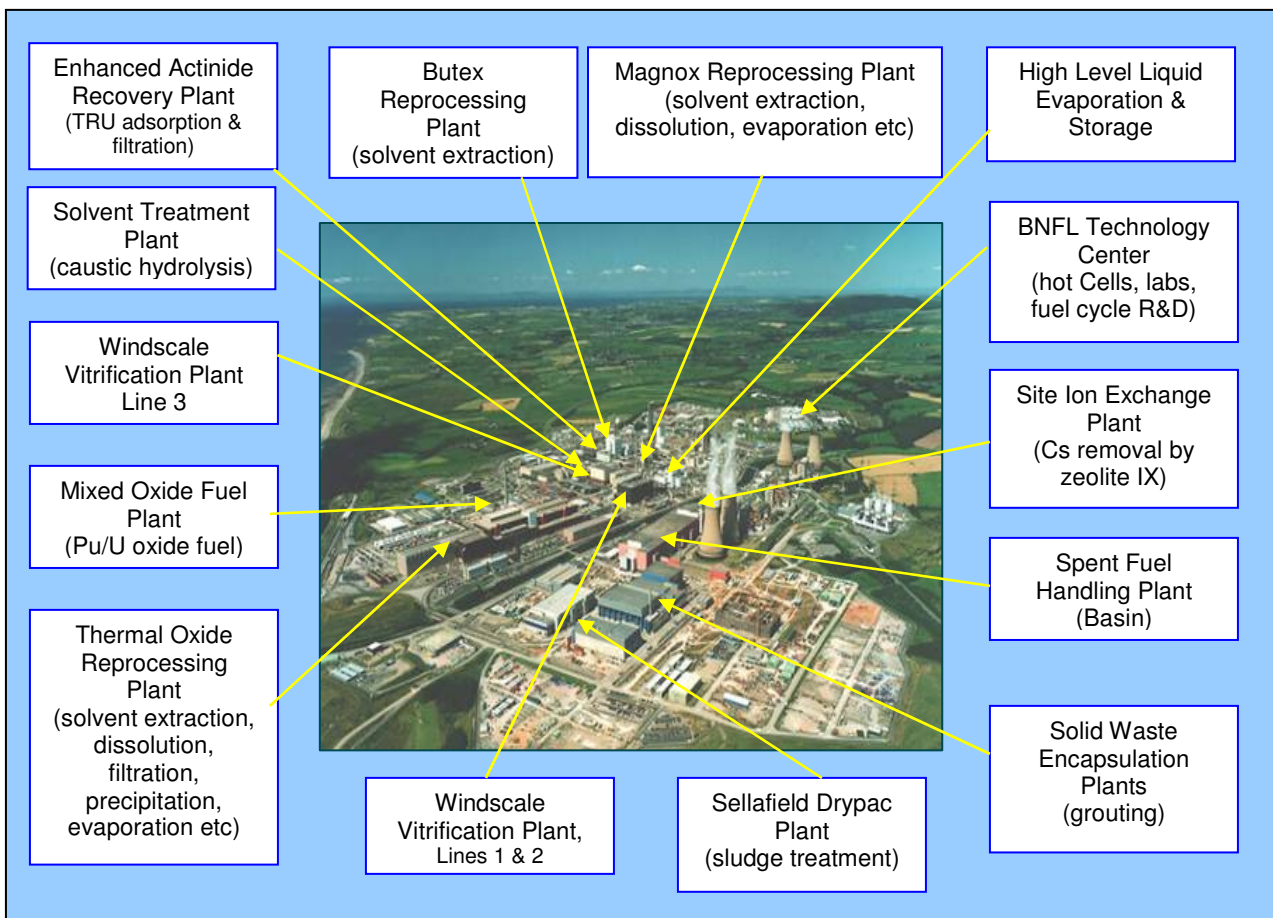


Figure 1: The Sellafield nuclear site in the United Kingdom

In 1956 the Calder Magnox nuclear reactors were brought into use which were dual purpose and generated electricity from the fission heat.

Three generations of spent nuclear fuel reprocessing plants have been built at Sellafield, with the “Butex” and “Magnox” reprocessing plants servicing the Piles and Calder reactors respectively. In the mid 1990s the Thermal Oxide Reprocessing Plant (Thorp) was brought into hot operation. This plant reprocesses solely civil, uranium oxide, nuclear fuel from the world’s Light Water Reactors and does so under full International Atomic Energy Agency (IAEA) and Euratom inspection and control.

In addition to these major plants, the site has a complete range of waste handling, laboratory, analytical, power & steam generating and administrative facilities.

Table I: Summary of Major Sellafield Site Plants

Plant	Purpose	Notes
Thorp: Thermal Oxide Reprocessing Plant	Reprocessing of irradiated U oxide fuel from worldwide reactors	Hot operation from 1994 to present. Third generation PUREX solvent extraction to separate U, Pu, FPs
Magnox Reprocessing	Reprocessing of irradiated U metal fuel from UK Magnox reactors	Hot operation from 1964 to present Second generation PUREX solvent extraction to separate U, Pu, FPs
Butex Reprocessing	Reprocessing of irradiated U metal fuel slugs from Sellafield Piles	Hot operation from 1952 to 1964 BUTEX solvent extraction to separate Pu
Fuel Storage Ponds (Basins)	Cooling, storage, handling, decanning irradiated fuel	Five ponds with three in use from early 1950s and now in cleanup Two modern ponds in current use
SIXEP: Site Ion Exchange Plant	Removal of radioactivity from basin water before recirculation or sea discharge	Hot operation from late 1970s to present Once-through ion exchange process
HA Waste Storage	Storage and evaporation of HA liquid waste from PUREX reprocessing	Hot operation late 1940s to present. Stainless steel tanks, acidic storage, evaporation to small volume
HA Waste Vitrification	Vitrification of HA liquid waste	Lines 1&2 hot operation 1990/92 to present, Line 3 2002 to present 2-stage calcination-melter process Waste needs no chemical pre-treatment
EARP: Enhanced Actinide Recovery Plant	Removal of TRU and Tc from waste streams prior to sea discharge	Hot operation 1993 to present. Uses ferric floc precipitation and crossflow filtration. Floc with TRU and Tc is cement-grouted
Cement Grouting	Immobilization of intermediate and TRU solid wastes, fuel cans and EARP flocs	Hot operation from mid 1980s to present Three separate plants produce drummed product Remote in-cell operation
Plutonium Finishing Lines	Conversion of plutonium nitrate solution to plutonium dioxide powder	Five lines with hot operation from early 1950s to present
MOX: Mixed Oxide Plant	Production of MOX U+Pu fuels for use in thermal reactors	Recycles Thorp U and Pu for customers
Technology Center	Research & Development to support all site processes and develop new ones	Opened in 2002 to replace existing scattered site facilities. Now operated by Nexia Solutions

Over the last 20 years, 20 new nuclear processing facilities have been added to the Sellafield site, at a cost of some \$15 billion, to support the site’s ongoing spent nuclear fuel recycling mission. While bringing on line this range of new plants, the average Sellafield plant operator radiation dose has been reduced by some 70% to a figure virtually identical to office based non-radiation workers,. The progressive refinement of the PSCs used in these plants has played a large part in this, by eliminating contamination spread and reducing hands-on maintenance requirements.

The Sellafield site now has over 200 facilities and is one of the most complex nuclear sites in the world. These facilities range from modern, efficient, low-dose, low-discharge plants that are in commercial operation, through to legacy, defense-related, plants that require cleanup and decommissioning. All the

plants handling high or medium levels of radioactivity have utilized PSCs throughout or in part. Because the Sellafield site was, until 2005, operated by its owner, it was a relatively simple matter to progressively feed back operating experience into the design of new plants, and there was a great incentive to do this. The design of the PSCs has thus been developed and improved over many years of practical plant experience. A more detailed description of the Sellafield site is given elsewhere [1].

USE OF PASSIVE, SECURE, CELLS AT SELLAFIELD

Table II provides examples of the number of PSCs used in the major facilities at Sellafield and shows the approximate operating life to date of each group of cells. This long operating experience has enabled the PSC concept to be progressively refined and robust design practices and codes to be established to supplement the US and UK national standards for nuclear plant.

Table II. Examples of Passive Secure Cell use at the Sellafield nuclear site

Sellafield Facility	Number of Passive, Secure Cells	Operating Life
First generation reprocessing facilities (Butex and associated plants)	10	1950 - 1973
Magnox uranium metal fuel reprocessing plant and associated facilities	15	1965 - present
Thermal Oxide Reprocessing Plant (Thorp) for uranium oxide fuel	30	1994 - present
Enhanced Actinide Recovery Plant (EARP) for TRU waste cleanup	5	1990 - present
Medium Active Waste Evaporation Plant	4	1965 - present
Highly Active Waste Evaporation & Storage Facility	15	1965 - present
Salt-containing Waste Evaporation Plant	3	1985 – present
Windscale Vitrification Plant – Lines 1 & 2	1	1985 - present
Windscale Vitrification Plant – Line 3	1	2002 - present
Solvent Treatment Plant	5	2002 - present
Magnox Grout Encapsulation Plant	1	1993 - present
Thorp Waste Encapsulation Plant	2	1994 - present
Total number of Passive, Secure Cells	92	

PSCs, and the equipment within them, are designed from the outset not to require any personnel entry for maintenance, modification or equipment replacement throughout the life of the facility. Nevertheless, means of internal inspection is provided via removable hatches in the cell wall and roof, and means of entry is also provided as a contingency measure, typically via doors that are sealed and shielded with blockwork on their outside. Camera inspections of the interior of the PSCs is regularly carried out and the Sellafield site has an expert team who do this as a routine task. Entry to the PSCs has been a very rare event indeed, with only two or three entries requiring to be made over the Sellafield site operation since 1950. When such entries are occasionally required, the absence of any spilled liquid that would arise from the routine removal of canyon-style pipe jumpers means that decontamination is more straightforward – with only the tanks and pipework to wash out.

DESIGN OF PASSIVE SECURE CELLS

There are three main types of Passive Secure Cell in use:

1. Enclosed cell containing sealed vessels and pipework only, with no equipment containing moving parts of any kind.
2. Enclosed cell with some rotating equipment within it, such as stirrers and low speed rotating bucket wheel type pumps (Constant Volume Feeders or “CVFs”). Drive shafts for this equipment protrude through seals in the cell wall or roof so that the motors and gearboxes can be located outside the cell. The in-cell equipment is designed with no mechanical bearings or any other maintainable items and this is achievable because of the slow rotational speed of the equipment.
3. Enclosed cell with more complex or higher rotational speed moving equipment units within it, such as centrifugal pumps, valves, filter elements and centrifugal contactors. This equipment is specifically designed so that modules containing all the moving and maintainable parts can be withdrawn from each unit into a shielded container or “flask” positioned immediately above the unit, on the PSC roof. The withdrawn module is then transferred to a separate maintenance cell, and a spare module can immediately be placed into service, avoiding prolonged plant shutdowns. This type of PSC was introduced initially for low to medium active environments but successful operating experience has now enabled its use for more highly active applications.

There are design principles and provisions that are common to all three types of PSC and also principles and provisions that are unique to types (2) and (3). Each of these will now be described.

COMMON DESIGN PRINCIPLES FOR PASSIVE SECURE CELLS

Construction and Access

PSCs are fully enclosed, mass concrete radiation shielded, structures with limited means of personnel access (Figure 2). The underlying intention with PSCs is to design out any requirement to re-enter the cell once it is placed into hot operation. Nevertheless, the risk of needing to re-enter at some point in the lifetime of the plant is assessed for each cell, and appropriate contingency measures are provided. For a PSC processing highly radioactive material, re-entry access is typically a steel containment door that is available for access during commissioning. Immediately before hot operation this door is closed and sealed, and concrete blockwork shielding erected on its outside, flush with the concrete cell walls. For PSCs processing lower radioactivity materials, a heavy steel shield door is used, locked and sealed shut, but without the extra concrete block shielding. In either case re-entry is thus possible, but requires the plant to be shut down and washed out and is thus not a routine operation. At Sellafield such re-entry has been a very rare event, amounting to only 2 or 3 occasions in the 50 year history of the site.

Internal inspection of PSCs by camera is however routinely carried out, and the Sellafield site has routine procedures and a specially trained team that carries out such inspections. These are done by removing tapered, concrete hatches that are located in the cell roof, and sometimes in the cell walls. The plugs are removed, once suitable temporary radiation shielding is in place, so as to allow the temporary installation of lights and remote control cameras within the cell. This means of access has also been used successfully to allow limited in-cell work, using remote controlled equipment, without the need to re-enter the PSC.

It is also possible to access the internals of pipes and tanks for inspection using small cameras and fiber optic endoscope devices that can be threaded through pipes, or through the cell wall plugs into access points built into tanks and other vessels. Use of such methods at Sellafield is rarer than routine in-cell inspections, but more common than cell re-entry. They have proved to be valuable techniques on the few occasions that in-cell pipework has suffered blockages. By identifying the location and nature of the blockage, suitable remedial methods have been designed and successfully used.

For certain equipment items, such as pulsed columns for solvent extraction, the internal assemblies of perforated plates are designed not to need any maintenance or replacement throughout the plant life. Nevertheless, provision is made to be able to access and remove the plates by assembling them in moderate length “cartridges” and providing access hatches in the PSC roof immediately above the

columns so that removal and replacement using the building crane could be done after suitable plant washout, if required. To date it has not been necessary to utilize these access arrangements.

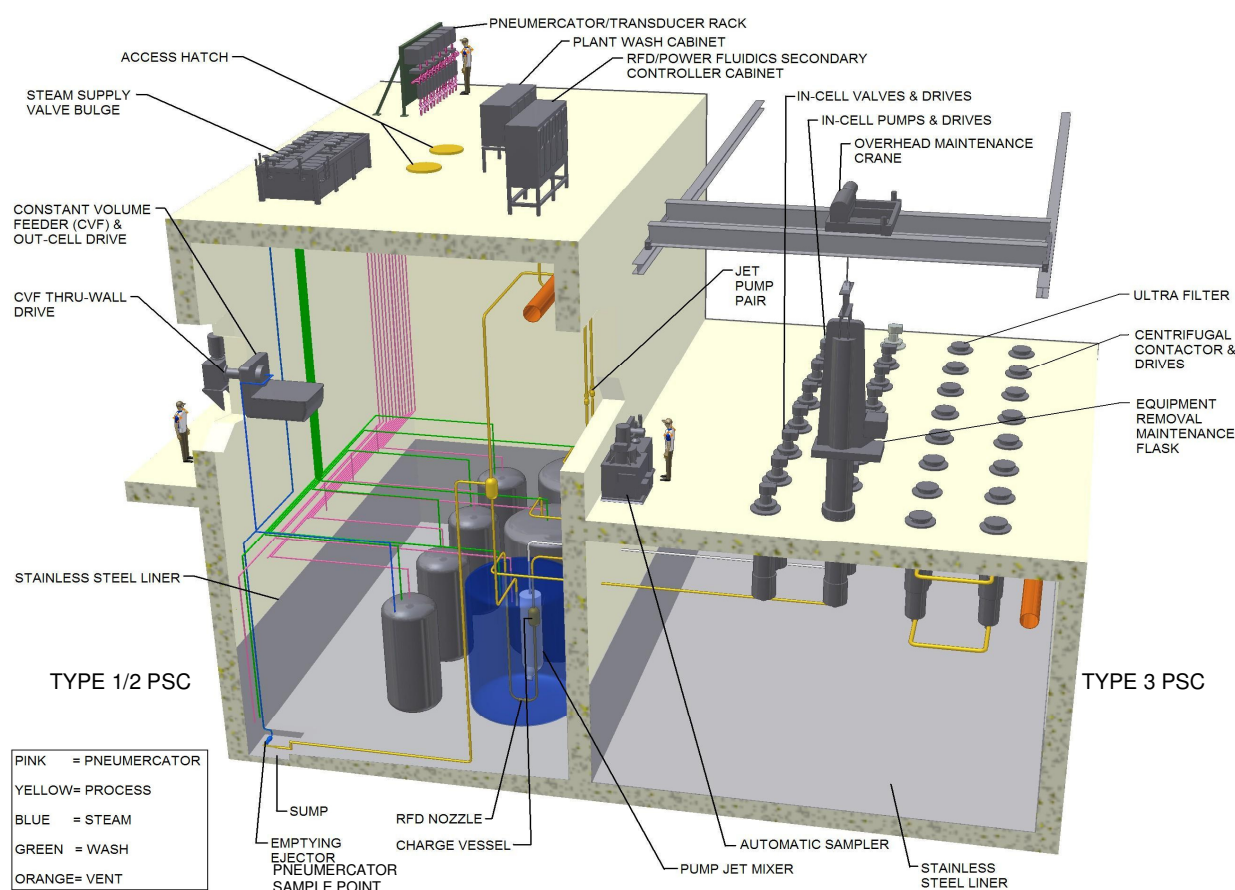


Figure 2: Major Features of Passive, Secure, Cells

Internal Design

The PSC is lined with stainless steel, at least up to the wall level that would be reached following a breach of the largest vessel within the cell, and in some cases to the top of the cell walls. This provides secondary containment for the process liquids. Welded seams in these linings are vacuum tested for leaks during construction and further leak tests are conducted during commissioning. A spray ring for wall wash-down completely encircles the PSC at the top of the stainless steel lining. The floor of the PSC is sloped to drain to a low point sump of a few gallons in volume. There are liquid level measurement devices (typically air-bubblers with a back pressure measurement, known as “pneumercators”) located within the sump, together with sampling devices, a means to inject water or acid, and a means of emptying (typically a steam ejector or fluidic pump). In the rare event of any leakage of liquid from the in-cell equipment, this will immediately be detected by the sump pneumercators, and the sampling equipment can be used to identify the constituents of the leak and hence its source. Recovery and wash-out is facilitated by the wash-down ring and emptying ejectors. The water/acid injection equipment is used to keep the sump “wet” and to periodically test the pneumercators by altering the sump liquid level and checking that this is detected. Leaks into PSCs have been extremely rare, with only one example in the last 20 or more years [2]. When this occurred, the design features described above proved completely effective in containing

the leak and enabling orderly and safe recovery. No radioactivity was lost from the plant, there was no contamination spread and no plant operator received any radioactivity dose as a result of the incident.

In-Cell Equipment

Equipment within the PSC is typically constructed from stainless steel or an even more corrosion-resistant material such as zirconium or titanium. Typically, all moving parts are excluded with the exceptions noted below for Type 2 and 3 PSCs. Vessels and pipework are of all-welded construction with every weld made to nuclear standard and fully radiographed. Pipework is designed with falls either to the discharging or receiving vessel, determined by individual analysis during design, and the application of standardized design principles and rules developed from many years of experience and operational feedback. Low or high points that would accumulate aqueous or solvent phases that could not be removed are avoided, or provisions are made to detect and allow removal of such accumulations.

In-tank level and density measurements are by air bubbler (pneumercator), and the associated pressure transducers for these and the cell sump pneumercators are located outside the cell in an instrument rack, normally located at more than a barometric head above the highest liquid level, so as to preclude any possibility of radioactive liquid backup into any out-cell area. If it is not possible to provide a full barometric head then other methods such as catch-pot isolation are used instead. Long experience and optimization of these designs has made them fully effective in the prevention of radioactive contamination spread to out-cell areas.

Liquid pumping is provided by steam ejectors, air lifts and fluidic pumps such as Reverse Flow Diverters (RFDs). Liquid mixing and agitation is normally provided by air-driven Pulsed Jet Mixers. These pumping and mixing methods have been described elsewhere [3]. They have been developed using purpose built test rigs and by the use of feedback from plant operators. When they are designed as units with the tanks and vessels they service, they are reliable and effective. Where there is a need to alter the route of a liquid flow, conventional valves are avoided by the use of Distributors (Figure 3). These consist of a chamber containing a movable “spout” through which the incoming liquid flows. The spout can be moved by an outcell motor via a through-wall drive so that it discharges the liquid into one of two or more outlet pipes.

Temperature, neutron monitors, ultrasonic probes and other self-contained sensors are fed from the outside of the cell through enclosed stainless steel tubes to a thin-walled pocket adjacent, or welded, to the plant item being monitored, so that they can be withdrawn and replaced without breaking cell containment.

Plant vessel washout is typically provided for by routing the in-cell pipework for the incoming washout reagents from the base of shielded “bulges” or gloveboxes (depending on the level of radioactivity) located outside the PSC to the in-cell vessel. The bulges and gloveboxes are normally located at least a barometric head above the highest liquid level in the in-cell vessels. The washout reagents, typically water, acid and steam, are provided by pipework entering at the top of the bulge or glovebox, but not permanently connected to the in-cell washout lines at the base of the bulge or glovebox. When washout is required, the appropriate reagent pipeline is connected by the operator to the required in-cell washout line using a flexible connector and quick-release couplings. When washout is complete the flexible connector is removed and stored within the bulge or glovebox. This method prevents inadvertent feeding of plant washout reagents to the plant when it is in production and also precludes any possibility of plant liquids backing up into the reagent lines.

All other equipment that needs periodic manipulation (such as air lift and fluidic air valves, steam ejector steam valves, sampling heads for collection of samples in bottles), is also located in shielded bulges and gloveboxes on the PSC roof. These bulges can be operated manually via manipulators or glovebox gloves, semi-automatically using remotely operated valves, or fully automatically, as in the case of autosampling devices [4].

Experience has shown that radioactivity can slowly “creep” up connecting pipes into these bulges and gloveboxes despite the existence of a barometric head. Suitable design provisions are made for this, including the provision of catch pot breaks in the lines, the provision of methods to wash down the connecting lines periodically, and the provision of local radiation monitoring and shielding equipment.

Ventilation

Ventilation of a PSC is effected by fan, through HEPA filters, to a stack, and is arranged in a cascade of air pressures. The PSC is maintained at the greatest depression (vacuum) relative to atmospheric pressure, the working area immediately around the PSC is at a lesser depression, and there are one or more lesser depression areas around that until ambient outside pressure is reached. Ventilation of vessel and pipes within the PSC is by a completely separate system, maintained at a depression greater than that in the PSC. This arrangement insures a cascading air flow from the area of lowest potential radioactive contamination to the highest. Because of the relatively small enclosed volume of a PSC, in comparison with a canyon, PSC-based plants generally have a lower air volume movement requirement, thus minimizing fan and filter sizes.

Contingency Allowances

A comprehensive understanding of the process and of the nature of the materials being processed is essential for effective PSC design. Detailed corrosion studies are carried out on both the process materials and on impurities that may be present. Suitable corrosion allowances are made when specifying the thickness of vessel and pipe walls, and in some cases more corrosion resistant materials such as zirconium and titanium are used for equipment particularly at risk, such as evaporators. It is common to operate evaporators at reduced pressure and hence temperature so as to minimize corrosion. Allowances are also made if especially abrasive materials are to be handled and these may extend to the provision of spare equipment built into the PSC from the outset, with extra through-cell-wall pipework connections (“wallboxes”) provided but not initially used. In some cases complete spare PSCs are provided to allow for future installation of equipment to replace items that are considered particularly vulnerable to failure in the long term. These include spent nuclear fuel dissolvers, where high temperatures and aggressive conditions are routinely present. The provision of such spare connections and PSCs, and the subsequent safe connection of them to existing radioactive plant (“active connections”) is another area of expertise that has been developed at Sellafield over its 50 year life and is now considered routine.

Waste Minimization

The use of PSCs minimizes the amount of radioactively-contaminated waste generated by the processing plants. In contrast to the canyon system where large items of failed equipment are routinely discarded and replaced remotely with new, the Type 1 and 2 PSCs produce little or no such equipment because all in-cell equipment is designed for the life of the plant. Because process equipment in Type 3 PSCs is specially designed with maintenance as a requirement, this allows solely the moving parts of failed equipment to be removed. A separate dedicated maintenance area allows their remote repair, mostly without the need for decontamination. Often it is only necessary to replace simple minor components such as elastomer seals to enable removed equipment to be returned to full service. Volumes of secondary solid waste are thus substantially reduced and the cost savings so realized have been shown to help outweigh any increased capital cost of PSCs and their specially designed equipment, after only a few years of plant operation.

General Design Standards and Provisions

Experience with PSCs over 50 years and over 305 km (1 million feet) of installed in-cell pipework at Sellafield has provided a steadily increasing knowledge base and has enabled EnergySolutions to build up a series of design standards that supplement Industry Standards such as ASME V111 and ASME B31.3. These design standards cover all aspects of PSC design:

- Shielding & confinement
- Ventilation systems

- Electrical systems
- Instrument & control systems
- Mechanical systems
- Utilities & services
- Liquid transfer devices
- Liquid metering devices
- Unit operations (eg: agitation, separation, filtration, melting, evaporation, heat exchangers etc)
- Duplication of equipment
- Criticality
- Fire protection
- All other events (eg: natural phenomena hazards, external events, common cause events etc)

Standard equipment designs that are tried and tested are available for use in new plant designs. Where it is essential to use novel equipment, this is rigorously tested at full or near full scale before inclusion in PSC designs. Particular consideration is given to the radiation and chemical resistance of all items to be contained within PSCs.

Where PSCs are not used

It should be noted that, where predominately mechanical handling equipment is to be used in a shielded enclosure, canyon type designs of cell are used. Value Engineering studies are typically carried out at the design stage to define where PSCs will be effective and where canyon-type cells would be more appropriate. So, for example, for spent nuclear fuel shearing equipment, fuel batch dissolvers requiring baskets of fuel hulls to be removed, fuel element dismantling and inspection facilities and similar mechanical operations, it would be ineffective to use PSCs. Instead, canyon enclosures are used with overhead and polar cranes within the enclosure, shielded windows in the walls, remote manipulators and similar equipment installed to allow operations to be carried out remotely. PSCs are used, on the other hand, when the cell is to be employed predominately for process plant with mainly pipes, tanks, pumps, separation and filtration equipment. All Sellafield canyon-type cells have shielded windows for internal viewing on at least one side; many have windows on both sides. Lighting units in the cell walls allow bulbs to be replaced from outside the canyon. PSCs are located separately and linked by shielded pipe enclosures, they do not surround the canyon.

DESIGN PRINCIPLES FOR TYPE 2 PASSIVE SECURE CELLS

Type 2 PSCs are a development of the Type 1 design. They accommodate limited amounts of relatively slow moving mechanical equipment. Typically these include stirrers for solvent extraction mixer settlers, constant volume feeders and the liquid diverters referred to earlier. Tank agitation can sometimes also be included but the higher rotational speeds and long shaft lengths make this less attractive than the use of Pulse Jet Mixers [3]. Some of the devices are illustrated in Figure 3.

Another type of penetration is the hanger system that suspends in-cell fissile material accountancy tanks onto load-cells located on the outside of the PSC roof. This allows the whole tank to be weighed to obtain an accurate volume measurement once the density is known from samples [2].

The common feature is a shaft that penetrates the cell wall or roof so that motors, gearboxes and load cells can be located outside the cell for easy, hands-on maintenance. For rotating shafts, the bearing and seal at the cell wall penetration is also removable, and thus replaceable, from outside the cell. This operation usually requires the erection of a temporary enclosure around the cell wall to contain any contamination that may escape while the cell wall bearing and seal is removed. In practice, because closed cells, by design, stay inherently clean inside, and because of the air movement into the cell caused by the cascaded ventilation system, such contamination escape is minimal or nil. For load cell suspension shafts, the seal is usually provided by some sort of elastomer bellows, normally double-walled with monitoring for radioactivity between the walls.

Type 2 PSCs have seen long service at Sellafield with mixer settler and constant volume feeder applications being in use since the early 1960s. During that time there has never been the need to maintain any in-cell equipment and all out-cell motor, gearbox and bearing maintenance has been carried out without incident or problem.



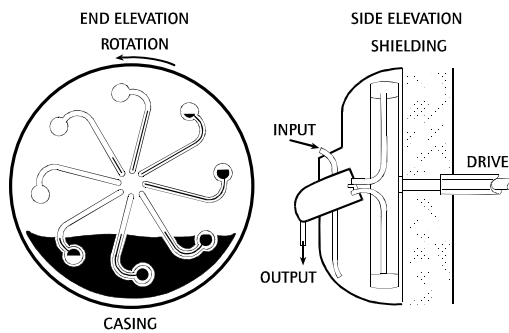
In-Cell Liquid Distributor



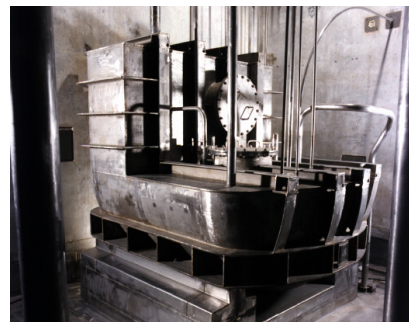
Mixer settler stirrer motors on PSC Roof



Mixer settler stirrer shafts under PSC Roof



Constant Volume Feeder showing through-wall drive



Constant Volume Feeder installed in a PSC

Figure 3: Some Examples of Type 2 In-Cell and Out-Cell Equipment

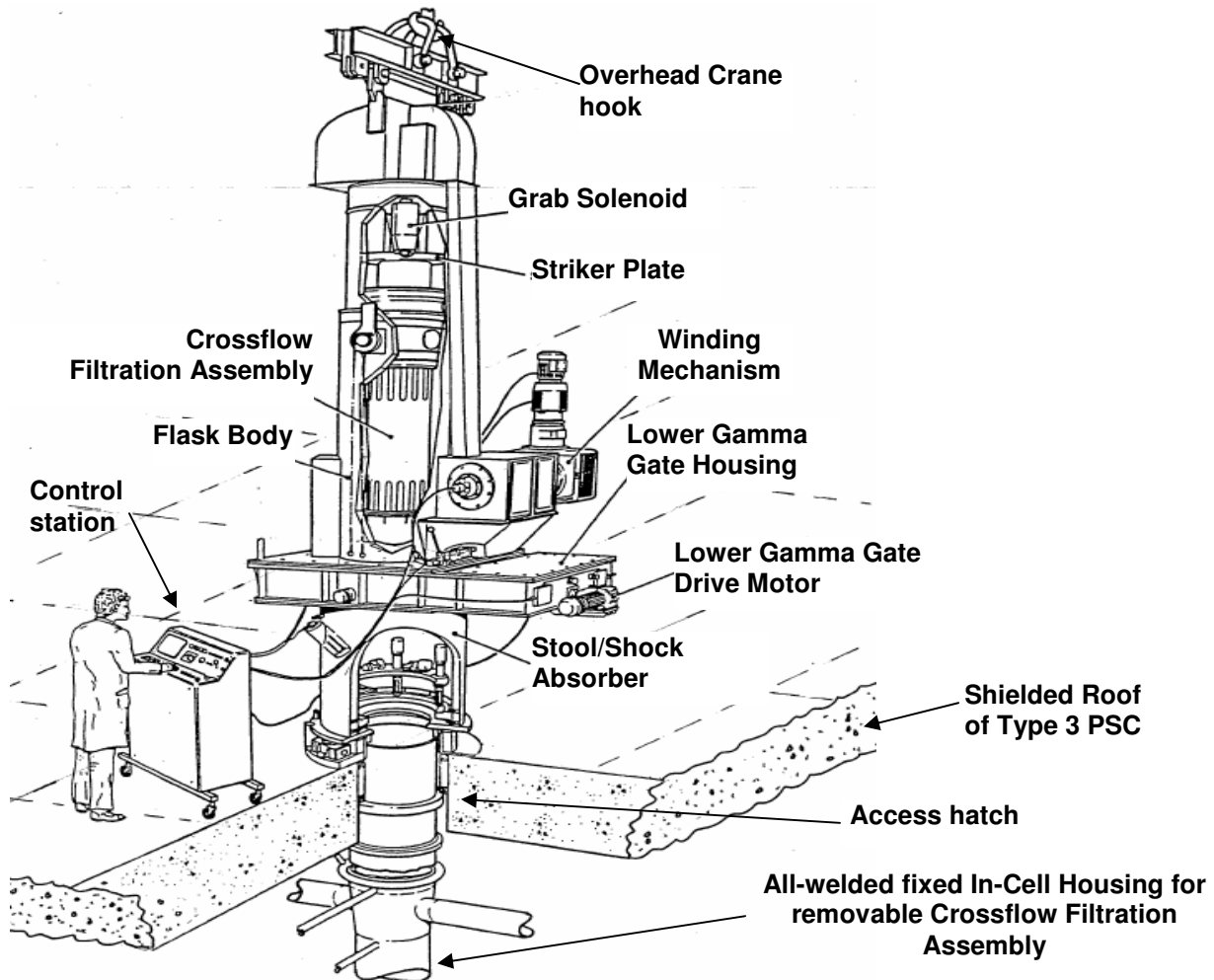
DESIGN PRINCIPLES FOR TYPE 3 PASSIVE SECURE CELLS

Type 3 PSCs have been developed more recently at Sellafield and can accommodate the use of more complex and higher speed rotating mechanical equipment within closed cells, while still allowing the moving parts to be remotely removable and hence maintainable. The general principles are shown in Figure 4 which illustrates the remote removal of a crossflow filter tube module into a shielded steel container or “flask”, temporarily positioned above an access hatch in the PSC roof.

Mechanical equipment typically installed in Type 3 PSCs includes pumps, valves, instruments and crossflow filter elements. EnergySolutions has worked with the manufacturers of these items to develop designs where all the moving parts are in a self-contained module that can be removed from the fixed housing that remains permanently welded into the pipework within the PSC. Liquid seals are typically provided by the use of elastomer O-rings which are removed with the modules and can thus also be renewed when maintenance is necessary.

Figure 4 shows a flask, gamma gate and stool in place over the in-cell housing for a crossflow filtration assembly with the assembly already withdrawn from its housing into the flask. The lifting equipment, winding mechanism and motor for withdrawing the filter assembly are integral with the flask, and are controlled by a movable control station that is hooked up to the flask as required. The flask is steel of a thickness appropriate to provide the required shielding for the withdrawn assembly. The removable

crossflow filtration assembly is shown in more detail below the main figure. When it is required to withdraw such an assembly from the PSC the steps that are followed can be summarized as follows:



Flask, gamma gate & stool in place on Type 3 PSC roof



Removable crossflow filter module



Typical Type 3 PSC roof with stools and gamma gates in position

Figure 4: Type 3 Passive Secure Cells, showing Flask, Gamma Gate and Stool on Cell Roof

- The crossflow filtration unit within the PSC is remotely isolated from other systems and then flushed with water and drained to remove residual process fluids and radioactivity.
- Physical tests and procedural checks are carried out to ensure that the unit can be removed safely
- The PSC roof has engineered sealed openings (“plugs”) that allow controlled removal of the filtration assembly. A portable gamma gate & stool are first positioned over the opening using the overhead crane.
- The flask is then positioned over the gamma gate and stool
- The PSC roof plug is removed and the gamma gate is opened, forming a sealed enclosure with the Flask, thereby ensuring continuing containment and shielding of the PSC contents.
- The grab solenoid and striker plate are lowered within the flask until they contact and fasten onto the top of the filtration assembly within the PSC.
- The assembly is raised into the flask using the flask integral hoisting mechanism. There are provisions in the flask to allow further washing by water spray if necessary to remove residual contamination as the assembly is removed. The washings are drained into an in-cell Plant Wash Tank for recycle.
- The gamma gate is then closed, sealing both the component in the flask and the equipment in the PSC below.
- The removed assembly, sealed within the shielded flask, is maneuvered using the overhead crane to a second gamma gate and stool permanently fitted to the top of a separate maintenance cell. The filter assembly is lowered into the maintenance cell from the flask, the gamma gate is closed and the flask is then removed for further use.
- The filter assembly can then be dismantled within the maintenance cell for repair or replacement of components. The most usual repair in EnergySolutions’ experience is replacement of the filter tube-to-tube plate elastomer seals. The tube bundle can then be re-used. If necessary the filter tubes themselves can be replaced, though in EnergySolutions’ experience this is rarely necessary.
- It is common practice to maintain spare filter assemblies in a second flask that can be immediately installed within the PSC, this minimizing plant downtime.

EnergySolutions’ development work with equipment manufacturers has allowed this concept to be extended to valves, pumps, and instruments, with each designed so that all moving parts can be remotely removed, leaving fixed housings permanently welded within the PSC.

Design work for the Salt Waste Processing Facility at the DOE Savannah River site also showed that this concept could readily be extended to the centrifugal contactors to be used for cesium solvent extraction. Following initial removal of the out-cell motor and gearbox for each contactor unit, the entire rotating bowl assembly can be removed from its in-cell housing into a flask, and replaced immediately with a spare unit.

Development of Type 3 PSCs allowed them to be used at Sellafield in the Site Ion Exchange Plant (SIXEP), used for ion exchange removal of trace cesium from fuel basin water, and the Enhanced Actinide Removal plant (EARP), used for floc precipitation removal of TRU and technetium from liquid wastes. The operation of these plants from the late 1980s to the present has been highly successful, allowing the Type 3 PSC design to be applied to cells containing more highly radioactive materials.

RE-ENTRY TO PASSIVE SECURE CELLS

Re-entry to PSCs once they have been placed in hot operation is not expected to be required during the plant life. Nevertheless, as is described under “Common Design Principles”, contingency means of access

via shielded doors is always provided. Use of these means of access has been a very rare event but has been effective when required. Two examples are given below to show how such entry is possible using the pre-planned design provisions and keeping well within worker radiation dose uptake limits.

Replacement of a Dissolver in the Magnox Reprocessing Plant

In the second generation Magnox uranium metal reprocessing plant, dissolution of the spent fuel rods into nitric acid prior to separation by solvent extraction is carried out in continuously fed, batch take-off, dissolvers, housed in Type 1 PSCs. In 1978, the “South” dissolver in this plant had been in use for many years and had dissolved some 10,000 tons of spent nuclear fuel. Routine inspections using the camera access previously described identified a small penetration of the dissolver vessel dome above the liquid level, due to vapor phase corrosion by an anticipated mechanism. Because of this anticipated failure, a spare “North” dissolver had been provided in the plant design and this was immediately brought into service, with the South dissolver shut down and washed out. Spare pipe penetration wallboxes built into the cell walls, and previous experience with safely making new radioactive connections, made this a straightforward and safe changeover.

Although the new North dissolver would have provided a similar period of service, this was determined in the mid 1980s to be insufficient because of the extension in operating life of the Magnox power stations in the UK and the consequent need for Magnox reprocessing until into the 21st century. It was therefore decided to enter the South dissolver PSC so that the old dissolver could be removed and a new one installed in its place. The dissolver and its associated process plant were washed out repeatedly over several months using nitric acid and water, so that radioactivity was reduced to a level that allowed engineering work to be conducted manually within the PSC. Entry was made using the installed doors after removing the blockwork shielding. There were a few “hot spots” within the installed vessels and pipework and these were dealt with by locally applied shielding. The internal surfaces of the PSC were not radioactively contaminated because they had been no spills of radioactive liquid within the PSC during its life. This was a crucial advantage over a canyon, where routine jumper removal would have resulted in spillage and contamination that would have been more difficult, if not impossible, to remove.

The old dissolver was cut up in situ for removal, but its replacement required a 13 by 16 foot (4 by 5 meter) opening in the PSC wall to be made. Advanced concrete cutting techniques were used to cut through the concrete and reinforcement bar in a controlled manner. After installation, the new dissolver had to be connected into the radioactive pipework in the North dissolver PSC, and this was achieved without shutting down the reprocessing plant by use of a robotic cutting and welding machine developed at Sellafield for such work.

The new South dissolver was successfully brought back into service and remains in full operation to the present, with the North dissolver providing a fully operational standby. The entire project was completed in a little over 12 months, without requiring any shut down of Magnox reprocessing. Worker radiation dose uptake during the work was managed in line with strict ALARA principles and normal working limits, well below legal limits, were adhered to.

Installation of extra neutron detectors in Thorp

After some 200 tons of spent nuclear fuel had been processed in the third generation Thermal Oxide Reprocessing Plant (Thorp)[2], the need was identified for some extra neutron monitors to be installed on one of the pulsed column solvent extraction contactors. This required guide tubes to be installed within the PSC, threading them through new apertures in the PSC wall and attaching them to the column walls. All process vessels within the PSC were emptied and washed out and the general radiation level within the PSC was reduced to 30-50 μ Sv/hr (3-5 mrem/hr). Entry to the PSC was via the pre-installed access door, after removal of the shielding blocks and unsealing the door. The work was completed within one month. The highest total dose to any individual worker was 520 μ Sv (52mrem), well within the legal limit of 20mSv/yr (2rem/yr).

OVERALL COMPARISON OF PASSIVE SECURE CELLS AND CANYONS FOR MODERN RADIOACTIVE PROCESS PLANT

An overall comparison is made in Table III of the features, benefits and drawbacks of PSCs and Canyons for modern radioactive processing plants.

Table III Comparison of Features, Benefits and Drawbacks of Passive Secure Cells and Canyons

Criterion	Passive Secure Cell	Canyon
Operability & Maintainability	Operation is entirely remote from the Control Room Maintenance is hands-on outcell or by infrequent removal of equipment in a purpose-built flask to a maintenance cell Only this flasking operation requires special training	Operation is by a mixture of remote from the control room and remote from the overhead crane operator. Maintenance is remote from the overhead crane and hands-on in the canyon maintenance area. Remote removal and manipulation of jumpers & plant items requires special training and skill More replacement of complete plant items likely so as to avoid radioactive maintenance. Maintenance likely to be needed more frequently because standard maintainable equipment is used
Reliability	Inherently reliable in-cell equipment. Motors, actuators etc are outside the radiation field so will not be degraded by radiation. All welded in-cell equipment eliminates leaks and resealing problems, and in-cell contamination	Normal process equipment with more frequent maintenance needs, exacerbated by radiation fields Use of jumpers leads to leaks onto canyon floor and to resealing problems at end of maintenance operations
Availability	Typical achieved availability is >90%	Availability likely to be in the 70-80% range depending on crane provisions, and degree of difficulty in resetting jumpers to get liquid seals
Space Utilization	Compact arrangement of process vessels in-cell because no access is normally required. No in-cell crane required, saving height Small volume minimizes HVAC requirements	Large in-cell volume required to accommodate overhead crane and space to remove the tallest plant items Large volume requires larger HVAC provision
Constructability	Welded pipework installation is straightforward and off-site constructed modules can be used. Need for 100% radiography of all in-cell welds is time-consuming	In-situ, individual final adjustment of jumper geometries is required to provide good seals. Seismic considerations complicate jumper and canyon design
Flexibility	Requires processes to be essentially fixed before major design is complete. Some flexibility in operation can be built in by the provision of spare cells and pipework connections	Vessel, process equipment and pipework can all be relocated within the canyon so design is inherently flexible
Maturity	PSCs have been used in the UK since the late 1950s and owner-operator arrangements have enabled extensive operator feedback of lessons learned	Canyon designs have been used in the USA since the 1940s and lessons learned are available to influence new designs
Radiation exposure: ALARA	Type 1 PSCs require no maintenance and so no operator radiation exposure Experience with Type 2 & 3 PSCs shows negligible dose uptake by workforce because of remote methods and infrequent need for them. Clean PSC interiors keeps dose uptake low during D&D	Leaks from jumper removals lead to slow build-up of radioactive contamination on canyon internal surfaces. Maintenance frequencies will be higher and some hands-on maintenance of contaminated equipment required. High potential for dose uptake during D&D
Contamination control	Fully welded pipework eliminates in-cell contamination Flasked out equipment does not come into contact with cell secondary containment	Leaks as jumpers removed give rise to potential for contamination. Maintenance crane can spread contamination throughout the canyon secondary containment
Decontamination & Decommissioning	Inside of PSC not contaminated so hands-on work possible once vessels and pipework washed out. However, only the access doors available to remove equipment so wall-cutting techniques may need to be resorted to, to remove large items	Crane and route out for dismantled equipment is already available However, inside of canyon contaminated during use from leaks during maintenance removal of jumpers. Experience has so far shown that this contamination is difficult to remove completely
Proliferation Resistance	Inherent because PSCs are sealed prior to introduction of nuclear material. Safeguards regulators additionally add their own seals because plant can be operated with them intact	Canyons cannot be sealed and so are vulnerable to potential diversion of nuclear material. Other controls must be applied
Capital and operating costs	Higher capital cost buys lower lifetime operating and maintenance costs and increased plant availability	Lower capital costs that can be reduced further by use of standard process plant equipment & instruments. Offset by higher lifetime operating & maintenance costs, and reduced plant availability

In summary, Table III shows:

- The PSC has advantages over the Canyon for operability, reliability, maintainability, space utilization, ALARA and contamination control. This is mainly because of the greatly reduced use of equipment requiring maintenance and the use of purpose-designed equipment for radioactive environments.
- The Canyon is more flexible for equipment re-configuration and changeout than the PSC. However, it is possible to re-enter PSCs to do modifications because only the process equipment is contaminated and not the cell floor and walls.
- The capital cost of a Canyon plant is generally less than one employing PSCs, but this cost advantage is generally reversed over the plant life.
- Technical maturity is similar for both Canyons with extensive experience in the USA, and PSCs with extensive experience in the UK
- Decommissioning is arguably simpler with a PSC plant, because only the process equipment requires decontamination. To set against that, a Canyon plant has easier access to cut up and remove equipment, but this will likely need to be done remotely because of residual contamination of the Canyon fabric.

The USA is currently contemplating a program of new nuclear power reactors and, via the GNEP initiative, is studying the recycling of the spent fuel and the transmutation of the long-lived transuranic elements in a new series of “Burner” Reactors that will also generate power. This will require the provision of recycling plants and other facilities handling highly radioactive materials. Consequently the design of these facilities, and the shielded enclosures to contain them, will require careful evaluation. It is suggested that the proven performance of PSCs in the UK is sufficiently compelling that they should be thoroughly evaluated for their use in the new US nuclear recycling plant build.

CONCLUSIONS

Highly radioactive processing plants using Passive Secure Cells and Canyons have been successfully built and operated in the UK and the USA respectively. The UK Sellafield build of some 20 new plants over the last 20 years, and the owner-operator arrangements under which these plants were run until 2005, has enabled the design of PSCs to be optimized.

Although PSC-based plants generally cost more to build than Canyon-based ones, this extra capital cost is more than recouped over the plant operating life. This is due to decreased maintenance requirements, decreased downtime and increased plant availability.

The operating and maintenance workforce of PSC-based plants generally receive radiation dose uptakes that are comparable to non-radiation workers. This is because of the low maintenance requirement, elimination of radioactive contamination spread outside the PSCs, and the automation of “radiation risk” tasks such as sampling process liquids.

For the new nuclear build currently being contemplated in the USA, it is suggested that the use of PSC-based plants should be thoroughly evaluated.

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