THE NEW VTT HOT CELLS

W.L. KARLSEN
Nuclear Safety, VTT Technical Research Centre of Finland, Ltd.
Kemistintie 3, FI-02044 VTT – Finland

F. BUTZE
Isotope Technologies Dresden GmbH
Rossendorfer Ring 42, D-01328 Dresden – Germany

ABSTRACT

The new hot cell facilities being constructed as a part of the VTT Centre for Nuclear Safety are aimed at the mechanical testing and microstructural characterization of beta- and gamma-emitting materials of nuclear power plant structures. The design includes a suite of six hot cells on the main floor, located above a utility cell in the basement, as well as a shielded glove-box/warm cell. The main floor hot cells are arranged in two rows with a closed access space between the rows, from which the interiors of individual cells can be accessed. Internal containments are a key design feature of the cells. A shielded, enclosed facility connects the two upstairs cell rows, and features a lift to transport test specimens from the basement utility cell to the connection cell with the primary purpose of conveniently transporting specimens between the basement and the two upstairs cell rows in a shielded manner.

1. Introduction

VTT has been hosting the Finnish national hot laboratory infrastructure since the first nuclear power plants were constructed in Finland in the 1970's. Historically the principle radioactive materials handling has been for the testing of reactor pressure vessel steels, but over time the activities have broadened to outgrow both the capacity and capabilities of the existing facilities. As such, a decision was made in 2011 to build a whole new facility, with the additional goal of gathering most of the VTT Nuclear Safety research personnel currently scattered around the Otaniemi campus, into a single, compact facility called the VTT Centre for Nuclear Safety (CNS). The facility would house new radiological laboratories and contemporary hot cells.

As described in a paper in the HOTLAB 2014 conference, the facility includes an office wing and a radiological laboratory wing. The office wing is 3,300 m^2 and includes a ground-level conference centre, above which are three floors of modern, flexible office space for 150 people. The laboratory wing includes a basement level and two floors of laboratory space. The laboratory activities include research involving radiochemistry, nuclear waste management, dosimetry, failure analysis as well as mechanical and microstructural characterisation of structural materials. Shipping radioactive materials into and out of the facilities occurs via the basement, through a gated courtyard and covered loading dock at the rear of the building [1].

The core of the hot laboratory is the hot cell facilities that enable safe handling of materials containing strongly gamma-emitting isotopes. A main activity is mechanical testing of radioactive materials, but there are also associated process such as electric discharge machine cutting, electron-beam welding and specimen preparation that need to be carried out in a shielded fashion. These shielding facilities will be installed in the high bay, which was designed to accommodate them. The high bay is a large, rectangular room 16 m wide by 25 m long, having a ceiling height of 8.6 m. At one end of the hot cell high bay is a large hatch that leads to the basement. Around the walls of the high bay is space for other, similar small constructions, and even test devices that can be shielded locally and enclosed in light glovebox containments.

The ventilation for the high bay is designed such that the hot cells will operate at an underpressure with respect to the surrounding air, and thereby a portion of the high bay air is exhausted by way of the hot cells, which are designed to include HEPA filters. This ensures that any radioactive contamination can be contained within the hot cells, which in turn minimizes the likelihood for contamination in the workspace around the hot cells.

To accommodate the expected load from the shielding cells, the floor of the high bay is a total of 75 cm thick pre-tensioned, reinforced concrete. The calculated load bearing capacity of the floor is 130kN/m^2 (~13 tons/m^2). The thickness of the slab also offers gamma radiation protection from the main-floor cells towards the basement, as well as from the basement towards the main floor.

A bridge crane runs the length of the high bay. It is designed to have 6 m of clearance below the hook, and a range covering the entire high bay. The specified design capacity of the bridge crane is 10 tonnes. The crane will be used during assembly of the hot cells during installation, and will also be useful for any partial disassembly when changing out equipment in the cells, removing manipulators for maintenance, etc. Another important use of the crane is for manipulating heavy casks in the high bay, as well as lifting casks from the basement through the hatch, and also manipulating large casks containing surveillance capsules into position at the basement reception cell.

1.1 Design input preparations

The design of the VTT CNS hot cells has been on-going since 2012. In the first phase the various activities to be carried out in the hot cells were identified, defined and described, providing a basis for subsequent design iterations. The potential risks associated with the hot cell activities were also considered as a part of a formal risk assessment. The conclusions of that process indicated that a high degree of passive safety is already accommodated in standard hot cells of modern design, but the process also gave important insight into how the working methods can be developed and deployed into the new facilities.

Because the hot cell design is also a strong function of the equipment to be installed in the cells, already in 2012 the investments were initiated for some key hot cell devices, including a pair of practice manipulators for developing in-cell methods and supporting equipment nuclearization, and some equipment to be integrated into the new hot cells, like a mechanical testing device and an electro-discharge machine. The investment program has continued since then at a steady pace, in order to assure that all technical requirements of in-cell devices can be accommodated in the hot cells, and to optimize timing of device delivery for nuclearization and deployment in the fabricated hot cells, and thus ultimately enable timely commissioning of the new facilities.

1.2 First conceptual design

With regards to the hot cells themselves, a significant milestone in 2013 was the execution of a hot-cell conceptual design and preliminary cost estimate, which was done on a contract awarded by public tender to Merrick & Company. Piecemeal descriptions of some of the processes to be included in the hot cells, and incomplete design basis specifications for all of the equipment and procedures to be included in the cells, required a series of assumptions to be made. The fact that the building itself had been largely designed already, with the space allocations having little flexibility, posed a further challenge. Nonetheless, the highest priority was to achieve a cost estimate in a timely fashion which had a basis in real fabrication and delivery terms.

The resulting conceptual design produced with Merrick consisted of two main parts; the main floor facilities comprised of a hot cell block and a small row of shielded glove-boxes, and the basement facilities comprised of three individual hot-cells for three different purposes. Their proposed solution utilized massive steel plates as the combined construction and shielding material, and cells with very large dimensions. Merrick placed a high priority on standardizing the cells as much as possible, regardless of a particular cell's ultimate purpose. This was somewhat successful for the main floor facilities, but was not easily deployable in the basement facilities, where the large size of the cells was a problem for the relatively low basement ceiling height.

The proposed layout of the main floor cell block was a classical arrangement that met many of the requirements for accessibility to the cell interiors for equipment maintenance etc., while maintaining a high level of radiation protection. Two adjacent rows of three cells each formed a relatively compact layout. The layout of the basement cells was mainly unsatisfactory from the standpoint that each of the activities included in the basement is very different from the other, and none are very amenable to the use of a standard cell.

The cost estimate provided by Merrick assumed that, since the cell unit was designed according to the highest source terms and largest piece of equipment, it produced a large, robust cell unit, which thus formed a conservative cost estimate. The total estimated cost was all-inclusive, delivered through Merrick as a turn-key proposition. As such, it included the detailed design phase, materials, manufacturing, fabrication, devices and components, shipping to Finland, and assembly for operation on-site, including on-site construction support. Merrick also provided an estimated cost for the different principle construction materials in terms of unit of equivalent shielding surface. Examination of the cost breakdown helped VTT to identify the principal cost factors, which was used to reassess the design inputs and produce a concept to put out for tender for the final engineering design and fabrication of the hot cell facilities.

1.3 Engineering design and manufacturing tender

The tendering process for the engineering design and manufacturing was carried out in 2014. For the new tender, the original concept was retained, but some modifications were made to reduce the size, eliminate separate standard hot cells for waste handling and autoclave testing, and to add a material transfer cell connecting the two rows of cells on the main floor, and a transfer elevator between the basement and main floor. The design also incorporated containment liners inside the shielding cell, which could reduce the manipulator reach requirements on the "hot" side, while also enabling more convenient and safe access by hand to critical parts of the equipment deployed in the cells.

The layout in the tender is shown in Figure 1. The main floor hot cells were to be arranged in two rows with a closed access space between the rows from which the interiors of individual cells can be accessed. A shielded, enclosed facility (referred to as cell 1.7) connects the two upstairs cell rows, and features a lift to transport test specimens from the basement cell 3.1 to the connection cell 1.7. The primary purpose of cell 1.7 is to transport specimens between the basement and the two upstairs cell rows in a shielded manner. The design and fabrication of this transport system is included in the contract. In addition, the contract includes three facility transfer casks that are matched to the transport ports in the cells as an alternative transportation route within the facility (e.g. to cell 2.1).

The principal cost factors were identified during the first conceptual design process. Thus, for the purposes of the request for tender, the cell number and dimensions were specified explicitly, to enable more direct comparisons between potential suppliers. The size and shielding wall thickness of the cells was specified in terms of lead-equivalent. The proposed distribution of shielding windows, manipulators and access ports was also specified. The contract was awarded to Isotope Technologies Dresden GmbH (ITD).

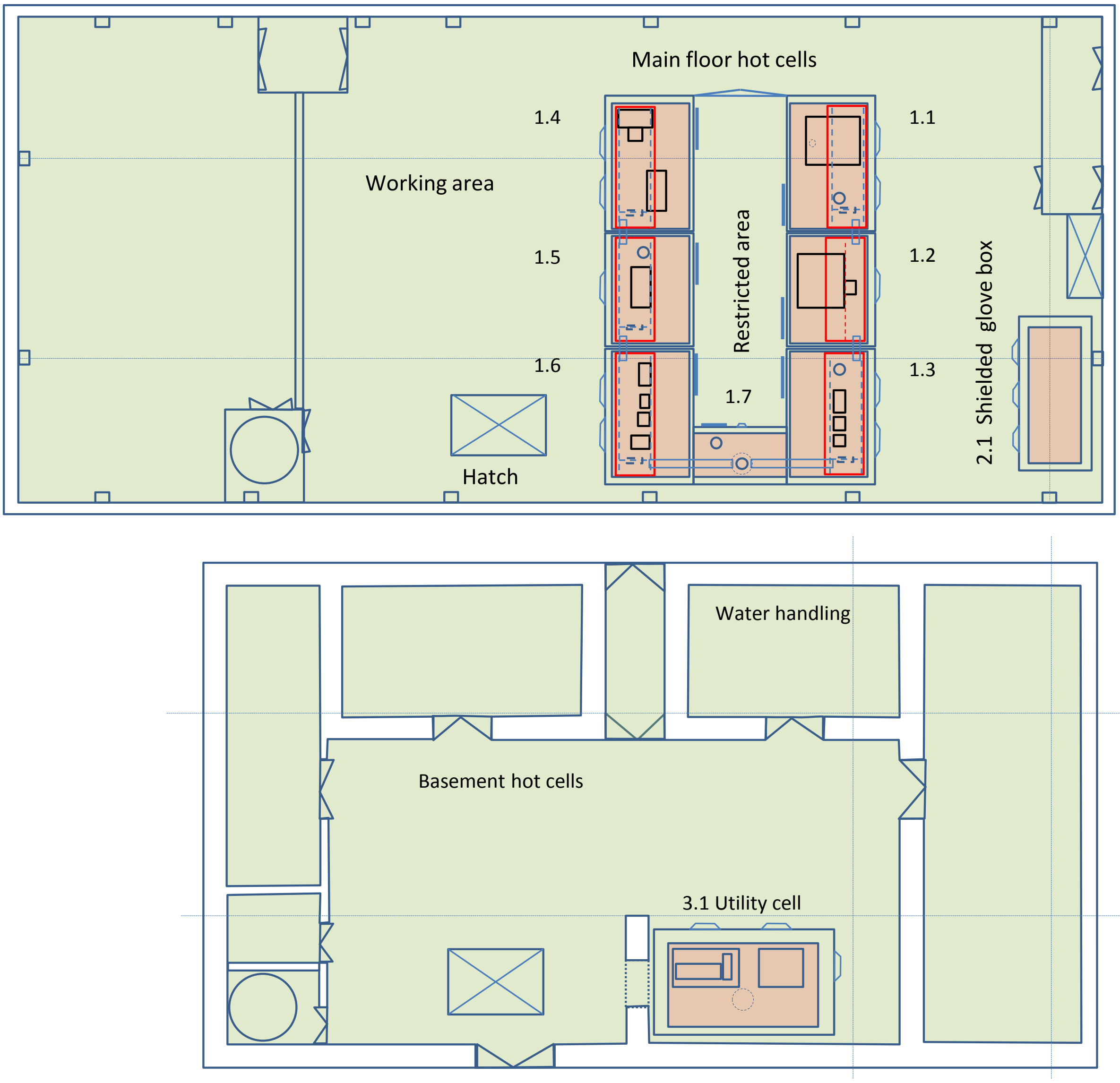

Fig 1. Layout of the hot cells with main working cells located on the main floor, connected to the utility/reception cell in the basement.

2. Final design of VTT hot cells

Per the tender specification, the main cell block is comprised of two rows of three cells each (1.1-1.3 and 1.4-1.6), connected by a transfer cell (1.7) containing the transfer elevator to the utility cell (3.1) in the basement. The main equipment locations remained as specified in the tender request, as shown in Table 1 and 2.

The first step in the engineering design phase was to update the conceptual design. Upon assessing the inner containment dimensions and aspect ratios, one of the principal design changes made, was to increase the number of work stations. That resulted in essentially two smaller work stations in each of the main cells (rather than one large one as first proposed), with each work station having a shielding window and a pair of manipulators. Offsetting the cost of increasing the number of windows and manipulators, was the utilization of smaller manipulators and some smaller shielding windows. Some of the less necessary manipulators were also left only as blind feed-through ports for realization later, as they become more relevant with the evolution of the activities inside the particular cell. In that way the functionality of the cells is greatly improved, but without cost increase.

Main floor hot cell		Equipment	
1.1	Machining	Electric discharge machine Drilling machine	GF CUT200 TBD
1.2	Machining	Electron beam welder	CVE 2010
1.3	Metallography	Cutting Hot moulding Cold moulding	Struers Minitom Struers CitoPress Struers CitoVac
1.4	Mechanical testing	Universal testing machine Environment chamber Impact tester Tempering unit	MTS 370.10 MTS 651.10E-04 Zwick HIT25 TZE unit
1.5	Mechanical testing	Universal testing machine HT furnace	MTS 810.10 Maytec HTO-08
1.6	Measurements	Hardness Specimen dimensions, Fracture surface documentation	Duramin A300 TBD TBD
1.7	Specimen transfer	Elevator	TBD

Table 1: Equipment of main floor cells

Shielded glove box		Equipment	
2.1	Metallography	Grinding Polishing Etching (chem. / electrochem.) Washing Drying Blanking, Thinning Optical microscope Stereo microscope	Struers TegraForce Struers TegraPol Struers TegraDoser Magnet stirrer Ultrasound washer Hot air blower Puncher 1/3 mm Struers Tenupol TBD TBD
Utility cell		**Equipment**	
3.1	Reception / Documentation Cask / Capsule opening Machining	3-axis linear milling machine Cutting band saw Rotation device Machine tables Storage cell Documentation equipments	Mirage MRY1500 TBD TBD TBD TBD TBD

Table 2: Equipment of shielded glove box and utility cell

2.1 Containment/Limit liners

Significant effort was also placed on determining the most appropriate dimensions of the limit liners, which are the principle containment within which the radioactive materials are to be handled. Outside of the limit liners the cells incorporate an access area, which allows manned access to equipment integrated into the cell, but only when there are no open radioactive sources present inside the containment. As shown in the layout drawing in Figure 2, the cells containing large equipment (1.1, 1.2, 1.4 and 1.5) in particular benefit from having shallower containments that reach from floor to ceiling, with a full-height manned access area behind for maintaining the large equipment. On the other hand, the intended operations in cells 1.3 and 1.6 mainly utilize table-top equipment, and therefore the cells are more amenable to deeper, “table top” containment, and there is no real need for easy manned access inside the shielding. Finally, to accommodate the transfer system in cell 1.7, a single containment was chosen for that cell, which is joined to that of 1.3 and 1.6, making it all a common airspace.

2.2 Mechanical Test Device Integration

An important aspect of the conceptual design is the integration of the small impact tester and the mechanical tester with associated environmental chambers. This is an area in which ITD has demonstrated experience, and therefore can design confidently. Examples are shown in Figure 3 based on ITD’s reference case in their tender, but the concept is very similar for cell 1.4, which will be developed in detail in the engineering design process.

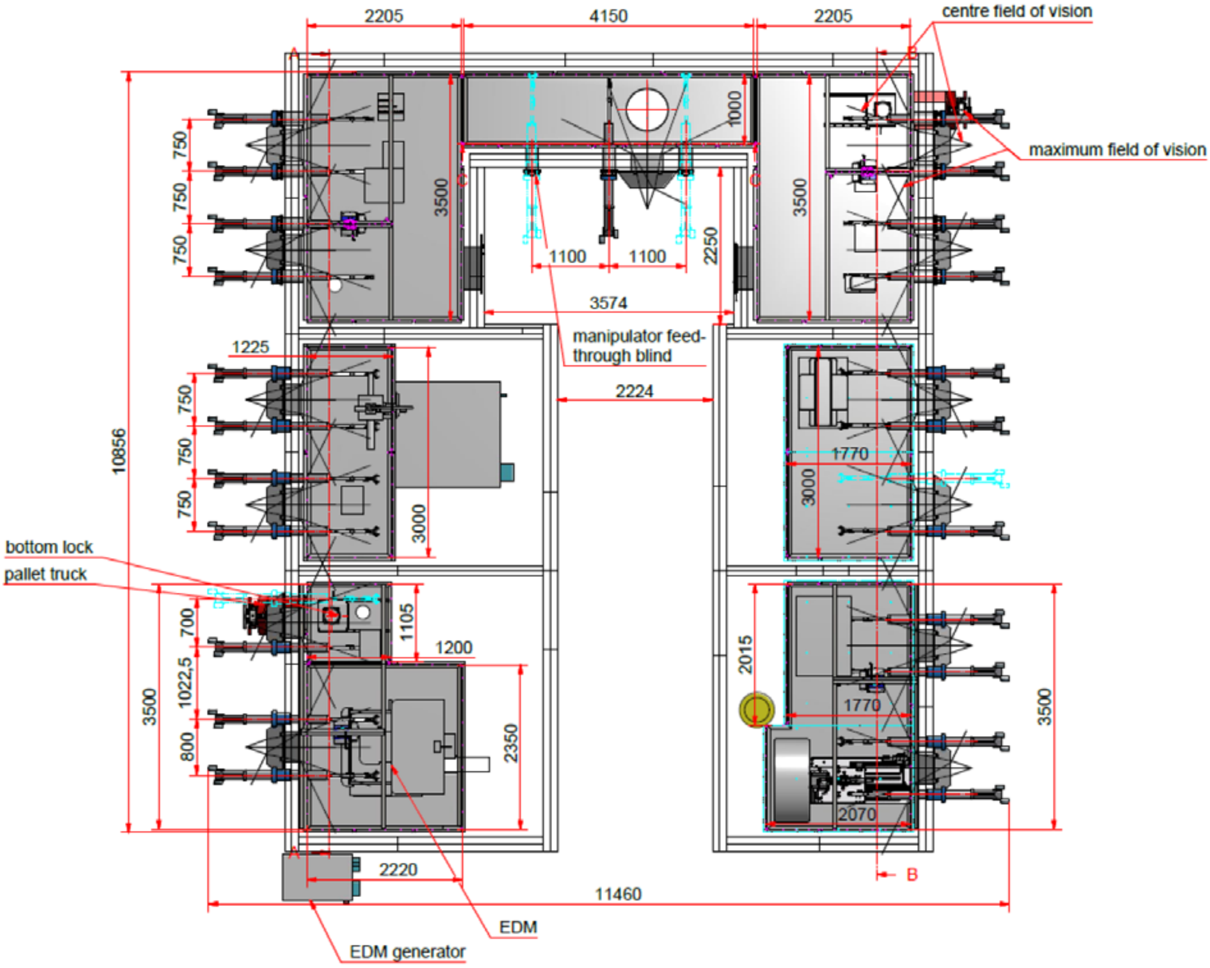

Fig 2. Layout of the shielding and inner containment of the main working cells (plan view rotated 180° with respect to layout orientation in Fig 1).

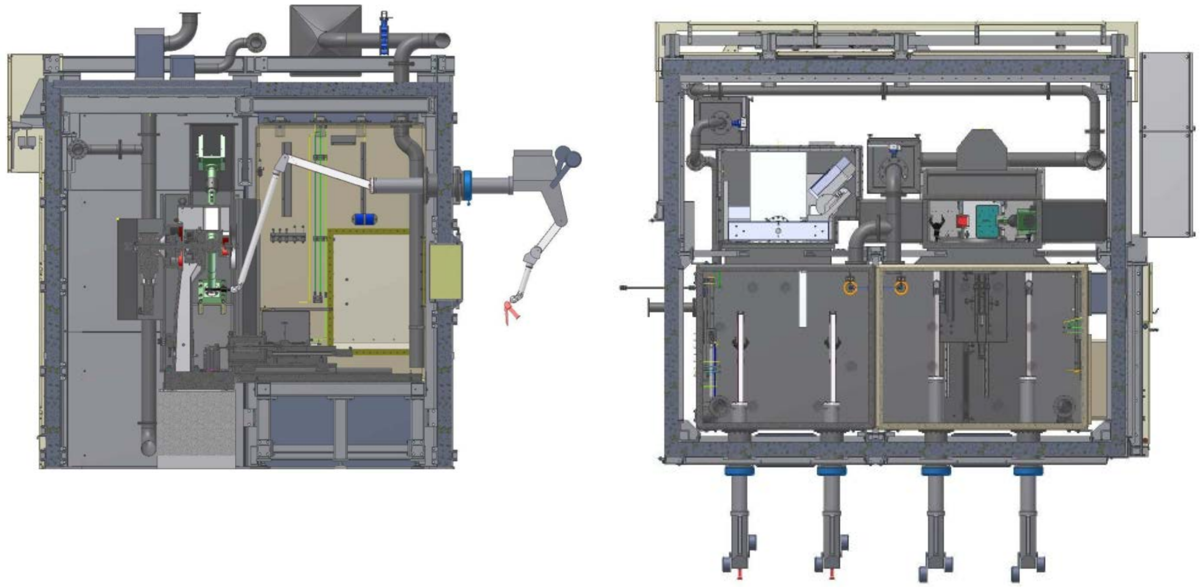

Fig 3: Integration of an impact tester and a tensile tester (both Zwick GmbH & Co. KG), similar to that for cell 1.4, viewed from the side in cross section (left), and from the top without cell roof (right). Like VTT cell 1.4, the working face has two windows and two pairs of manipulators, and an access area in the rear of the cell for device maintenance, while the area for radioactive test specimens handling is a separate containment.

2.3 Shielding

The gamma shielding consists of conventional lead “chevron” bricks in a welded steel frame. The particular thickness of lead shielding in different locations was also reassessed by ITD, enabling less shielding material to be employed in some areas, yet without significantly diminishing the safety. This was done based on the initial shielding calculations carried out by ITD using the specifications provided by VTT.

The shielding calculation results confirm that the specified dose-rate of no more than 1.5 microSv/hr is achieved at the front working face. The final shielding thicknesses in general adhere to the principal of the most shielding being at the face of the cells where personnel spend the most time (200 mm Pb in the main cells), less shielding in the rear of the cells and between the cells where personnel access is less frequent (150 mm Pb in the main cells), and even less shielding at faces where personnel or the public have no proximity (main floor cell roofs and high bay exterior walls) or where concrete is also offering additional shielding. The shielded glovebox (2.1) is designed for smaller radioactive sources, and so the relative thicknesses are less (mainly 100 mm Pb) as compared to the main hot cells, and likewise, the basement utility cell (3.1) is designed for accommodating hotter sources, and so most faces have 250 mm of lead shielding.

With the lead shielding thickness and layout established, the loading plan for the main hot cell group was calculated. The structural design chief of the Centre for Nuclear Safety utilized the plan to confirm the adequacy of the load capacity planned for the floor of the facility’s hot cell high bay.

2.4 Shielding windows

The tender specification called for hot cell shielding windows on the order of 700 mm wide x 400 mm high, with each glove box windows on the order of 300 mm wide x 200 mm high. Most cells included only one window per cell. As illustrated in Figure 4, ITD carried out an assessment of viewing angles, and proposed reducing the window size to 400 mm wide and 315 mm high and increasing the number of windows in some instances, to better accommodate the proposed work station layout in the main hot cells while assuring good visibility.

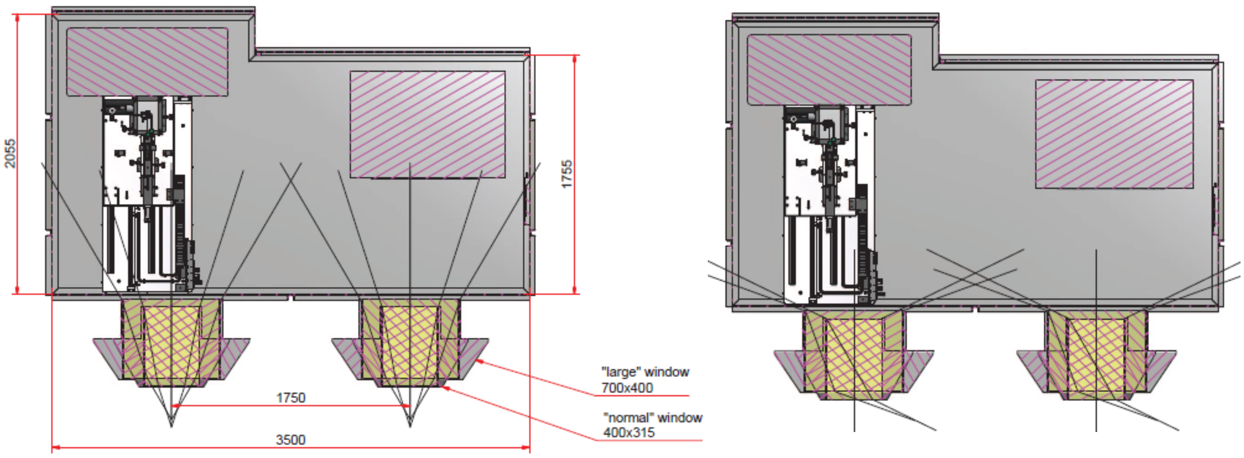

Fig 4: Window viewing angles comparison for larger and smaller window alternatives for normal viewing (left), as well as extreme viewing angles (right).

2.5 Ventilation

Another important aspect of the radiological safety of the concept is the ventilation system. The approach chosen with ITD for the hot cells is a controlled airflow cascade leading from the “cleanest” areas to the “dirtiest” area inside the containment liner, produced by strong under-pressures. There is a negative pressure in the hot cells, but no defined low pressure in the service area behind hot cells and corridor. While the corridor and service area are enclosed to a certain degree, there is no low pressure in the service area and corridor related to the environment (room), but corridor and service area are together designed in such way that holes, gaps etc. are eliminated. Nonetheless, the corridor and service area are ventilated due to the directed flow, whereby the main supply air will enter by pre-filters (low filtration class) and valves on the roof of the corridor, from there air goes through pre-filters with valves into each cell’s individual service area, and from there the air goes through valves and HEPA-filters into individual containment enclosure. The air leaves the containment enclosures by valves and HEPA-filters into a combined exhaust air tube, and the exhaust air tube is connected to the site ventilation system. The corridor itself has an auxiliary waste air exhaust for adjustment of air flow, but the main air flow will go through the hot cells, where it is controlled by exhaust valves in each containment enclosure.

2.6 In-cell and inter-cell transport and access

Another significant feature of the cell design is the various access and transport routes. These must accommodate both the dimensions and weight of the items. These comprise ports, which enable transport of materials into, out of, and between cells, as well as manipulation and lifting devices. Besides the less frequent need for manned access and equipment installation or removal, there is the day-to-day flow of materials and waste within the facility. This is shown schematically in Figure 5.

2.6.1 Cell 1.7 transport system.

A customized hoist and horizontal transport system has been developed for cell 1.7, which enables fully shielded distribution of specimens between the basement and main floor, as well as between the two cell rows on the main floor. The functional principle is shown in Figure 6. One reason for employing such a system over simply using a facility cask is that a large number of test specimens come from RPV surveillance capsules, which are opened in the basement utility cell. Temporary storage of the recovered specimens is also foreseen in that cell. Subsequent distribution to the mechanical testing cells can thus occur directly via

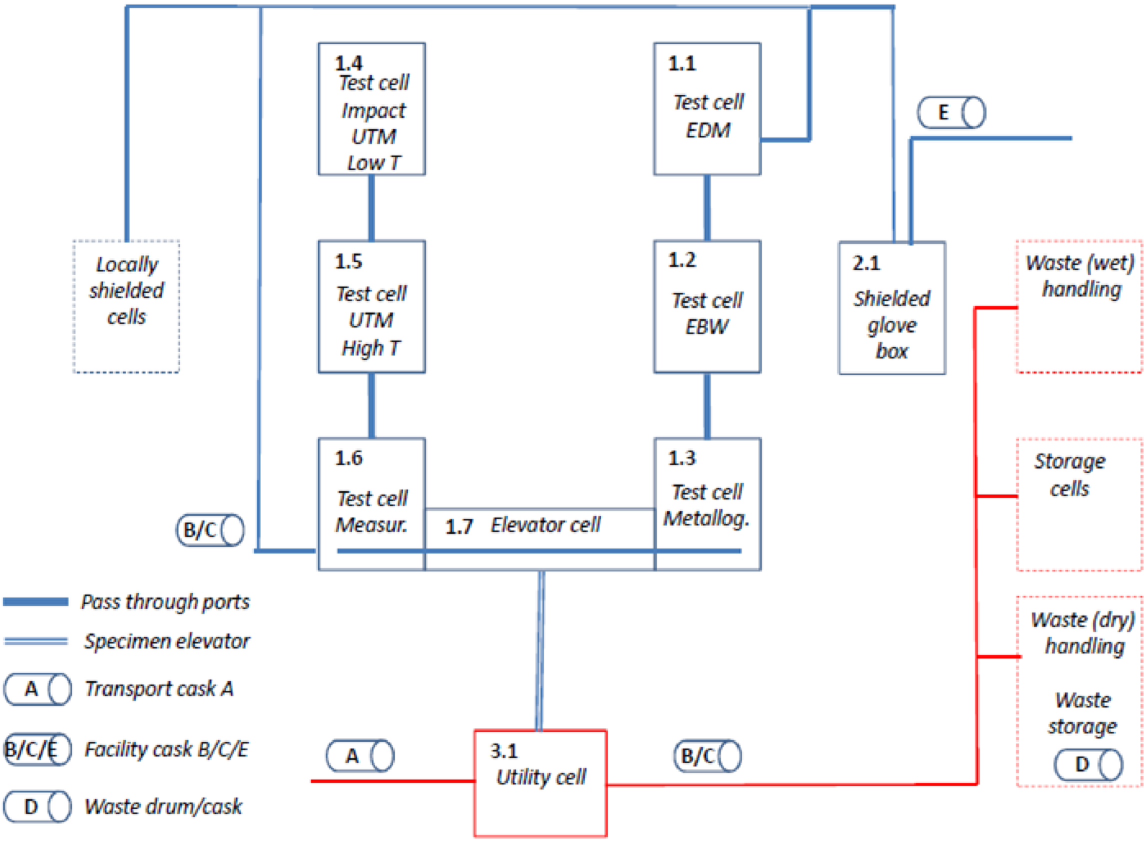

Fig 5. Material flow in hot cells and their supporting facilities. The red lines denote transports in the basement, the blue lines denote transports on the main floor.

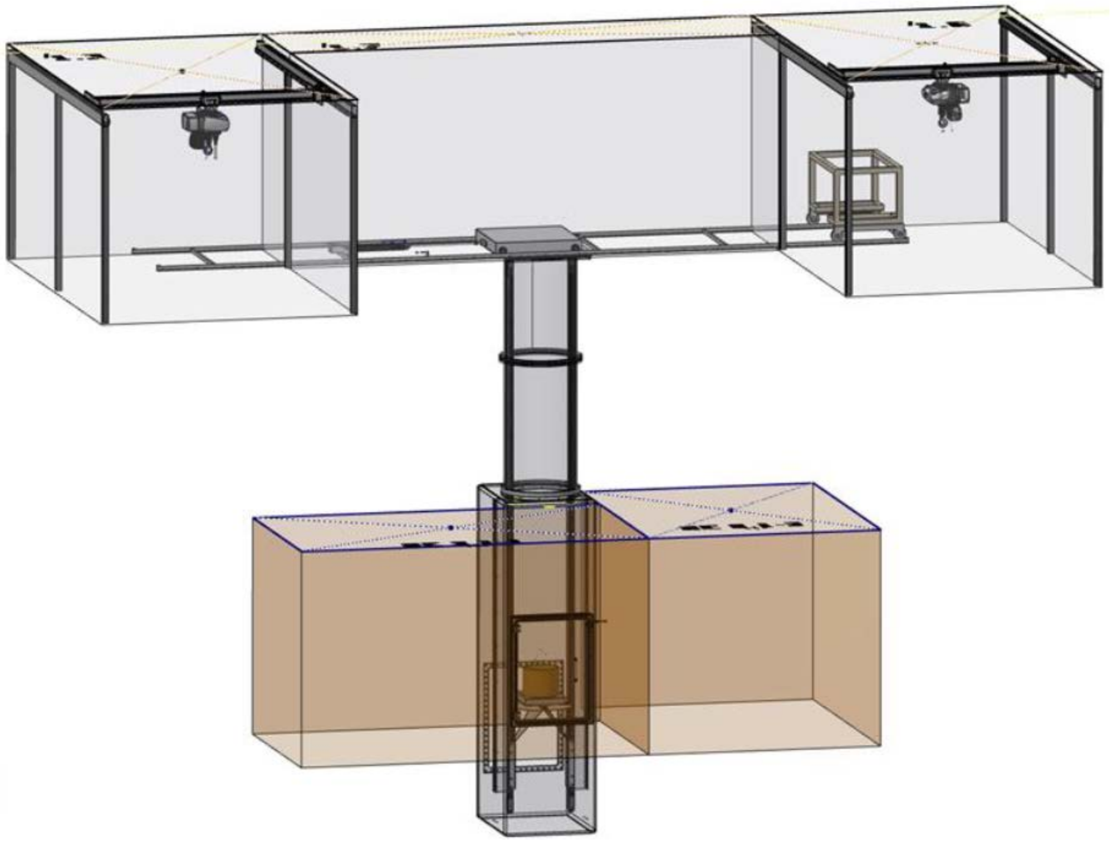

Fig 6. ITD custom-designed shielded transport system (Cell 1.7) connecting the basement utility cell 3.1 with the two rows of cells on the main floor, allowing both vertical and horizontal transport.

Cell 1.7. Likewise, in cases where fractured mechanical test specimens are reconstituted into new test specimens, there are also frequent transfers between the testing line (cells 1.4 to 1.6) and the manufacturing line (cells 1.1 and 1.2), which can happen quickly via cell 1.7. The specimens will be carried in small baskets. An option is that the baskets could bear bar-codes, to facilitate tracking of specimens through the different workstations.

2.6.2 Ports

Ports are designed to enable operation while retaining the integrity of the containment. They are used at pass-throughs in the walls between cells, and for access from the outside. In the current design there are pass-through ports between adjacent cells in the main working cell block (1.1-1.2-1.3 and 1.4-1.5-1.6). Since 1.6, 1.7 and 1.3 are a single air-space, ports are not used between them. There is also a docking port for a facility cask in cell 1.6 and in cell 1.1, as well as in Cell 2.1 and Cell 3.1. A typical docking port is shown in Figure 7. Docking ports for both horizontally-loaded and vertically-loaded transportation casks are also incorporated into Cell 3.1, which is designed to flexibly handle the casks of external transports.

The basic pass-through port between cells uses a double-door design, whereby only one door is open at a time. The space between them is dimensioned to fit a waste container. Each of the doors has a shielding factor equivalent to ½ of the between-cell shielding requirement. In the case of a docking port, the cell-side door has the same shielding factor as the cell floor, and when the cask itself is raised up to the port, the interface has an inflatable seal that assures maintenance of the cell containment once the port's door is opened.

2.6.3 Access doors

In the case of manned access to the maintenance area behind the heavy cells, a door is used that has the same shielding factor as the wall it is mounted on, as illustrated in Figure 7. Because it is heavy, it hangs from a robust guide, and can also have rollers on the bottom, sliding open to the side rather than in a hinged fashion. Such service entrances are employed in cells 1.1, 1.2, 1.4, 1.5 and 3.1. Several of the cells also contain plug-type access allocations in their roof, for cases of changing out bigger pieces of equipment (1.2, 1.3, 1.4, 1.5, 1.6), and/or smaller access doors in one wall for exchange of small devices and instruments through the liner (1.3 and 1.6).

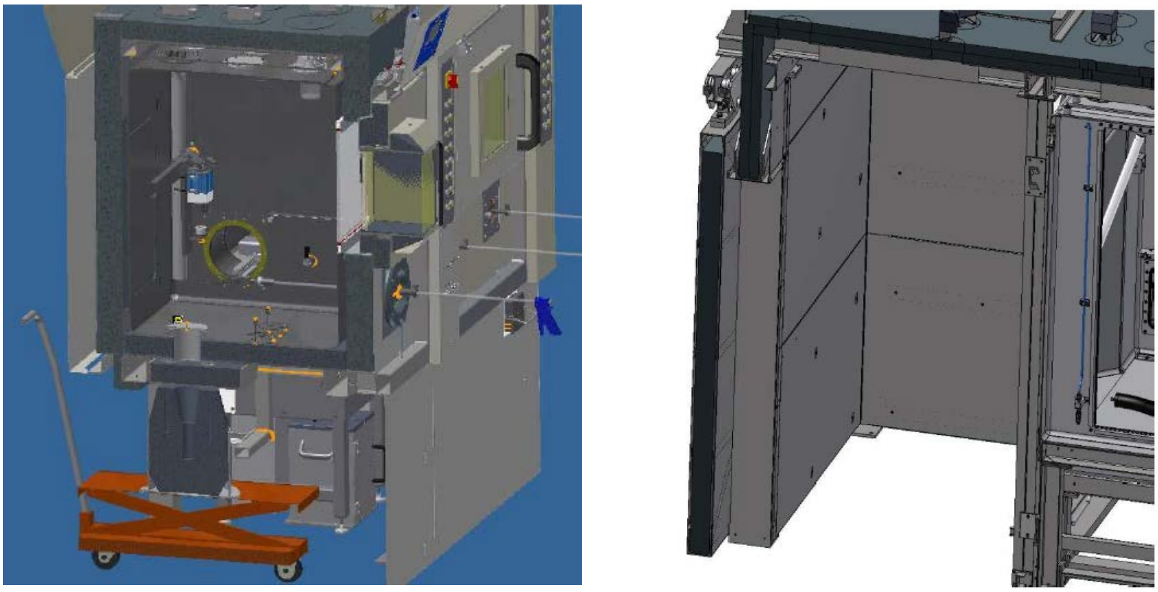

Fig 7. Example of a bottom docking port with a shielded facility cask (left), and a cross section through a rear access area of a cell (right). The door section is on the left side, while the inner containment is shown on the right. The access area enables hands-on maintenance of cell-related equipment when the radioactive sources are covered or removed from inside the containment.

2.6.4 Manipulators and hoists

Each work station generally has a pair of master-slave manipulators. Such manual MSM are important for the 1:1 replication of movements by the slave arm inside the containment. In a few specific locations, mainly the shielded glove box 2.1, ball-tong type manipulators produced by ITD are utilized. For augmenting the manipulators, an in-cell bridge crane/bi-rail hoist is included in cells 1.1, 1.3, 1.5 and 1.6. The capacity is 100 kg, with an electrical vertical hoist, and free-wheel horizontal motion guided by a manipulator. A similar one will be deployed in cell 3.1, but with a greater lifting capacity.

3. Conclusions

The hot cell design developed by ITD in collaboration with VTT shows that a positive evolution of the design towards greater functionality and feasibility was successfully achieved. While the final engineering design includes a number of different aspects of the design beyond just the layout, containment, workstations, shielding materials and ventilation approach, this document describes the main cost factors that have been fixed in the evolved conceptual design. Things like power cabinets, electrical in-cell sockets, in-cell vacuum cleaners, radiation monitoring system and cell feed throughs will be further developed in the engineering design phase. Nonetheless, the resulting evolved concept adhered to the initial tender specification document produced by VTT, with the main exception of the layout of the work stations. The increased number of work stations can be justified based on the facts that smaller manipulators are required, and smaller windows can be utilized at each station, while increasing the versatility of the activities that can be accommodated in each cell.

4. References

[1] W. Karlsen, “The new VTT Centre for Nuclear Safety,” Proceedings of the 52nd HOTLAB meeting, Baden, Switzerland, September 21-25, 2014, 18p.