Development and Design Considerations for a Suite of New Post Irradiation Examination Hot Cells to be Constructed at McMaster University

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Abstract. McMaster University, Hamilton, Ontario, houses the McMaster Nuclear Reactor (MNR), the highest flux university research reactor in Canada. MNR is a 5 MW_{th}, light-water cooled and moderated, LEU fuelled, pool-type reactor. A single support hot cell also exists but is not suited for PIE. A suite of new PIE cells will be designed, constructed, and installed in room 105 of the Tandem Accelerator Building (TAB). The objective of the capability is materials characterization research at the atomistic level. This paper presents planning, design, and construction considerations associated with the new cells. The project poses a three-way contest among limited available space, maximum desired PIE capabilities, and funding. [The Canada Foundation for Innovation and the Ontario Ministry for Research and Innovation are jointly funding the project.] Maintaining other tenants' use of the TAB complicates design and construction. The concept includes initial sizing of large specimens, such as entire CANDU pressure tubes, elsewhere, plus six new cells in the TAB to perform: receipt and shipping, non-destructive examination, waste management; machining; preparation of mechanical test specimens; mechanical testing; preparation of microscopy specimens/light microscopy; long-term mechanical testing; and specimen archives. The first cell is highly shielded, to allow handling of maximum size and activity specimens. The remaining cells will handle smaller specimens, typical of PIE microscopy, and the cells are modular of all steel construction. In-cell capabilities and equipment include: material transfers - input and output; one pair of manipulators; in-cell lifting equipment; in-cell lighting, utilities, fire protection; HVAC connections; work tables or equipment stands, and specimen preparation and testing equipment (including focused ion beam (FIB) apparatus . A transmission electron microscope (TEM) and scanning electron microscope (SEM) are also located in the same TAB room, with both pneumatic and manual shielded container transfer capabilities.

1. INTRODUCTION

The McMaster Nuclear Reactor (MNR) is a low enriched uranium-fuelled (LEU), light water cooled and moderated, 5MW_{th} pool type reactor located at McMaster University, Hamilton, Ontario, Canada. The MNR is the highest flux university research reactor in Canada. A recent major infrastructure grant has been awarded to McMaster by the Canada Foundation for Innovation and the Ontario Ministry for Research and Innovation to establish the Centre for Advanced Nuclear Systems (CANS). This centre will have new facilities for post irradiation examination, a 3-D atom probe, SEM/FIB and TEM facilities for both irradiated and un-irradiated material, all of which will support materials characterization research at the atomistic level. Additionally, CANS will have facilities for new alloy development and supercritical water mechanical testing of materials supporting research on Gen IV nuclear reactors and a new facility for safety thermal hydraulics experiments.

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The University has the faculty expertise, instrumentation, and research support to conduct materials characterization (i.e., post irradiation examination (PIE)) of irradiated materials at the atomistic level, but does not have the shielded facilities required to perform sample preparation and testing. CANS will establish that capability.

Beginning with the first exploratory discussions between the university and the facility designer, it was clear that the space available for construction of the PIE facility was limited, but that compensating limits to the scope of PIE operations were possible.

Consideration of existing permits and licenses, as well as adjacent support facilities (such as change rooms) led to the decision to locate the hot cells in room 105 of the TAB. Fig. 2.1. shows the location of room 105 within the TAB.

Design bases, space limitations, and the resultant conceptual design are described in subsequent sections [Design, construction, and operating costs are also an overall consideration, but costs are not within the scope of this paper except as discussed with regard to specific design decisions.].

2. DESIGN BASES

The essential design bases for the PIE facility are:

- The design will meet requirements and guidance of Canadian Nuclear Safety Commission (CNSC) guide-52 [1];

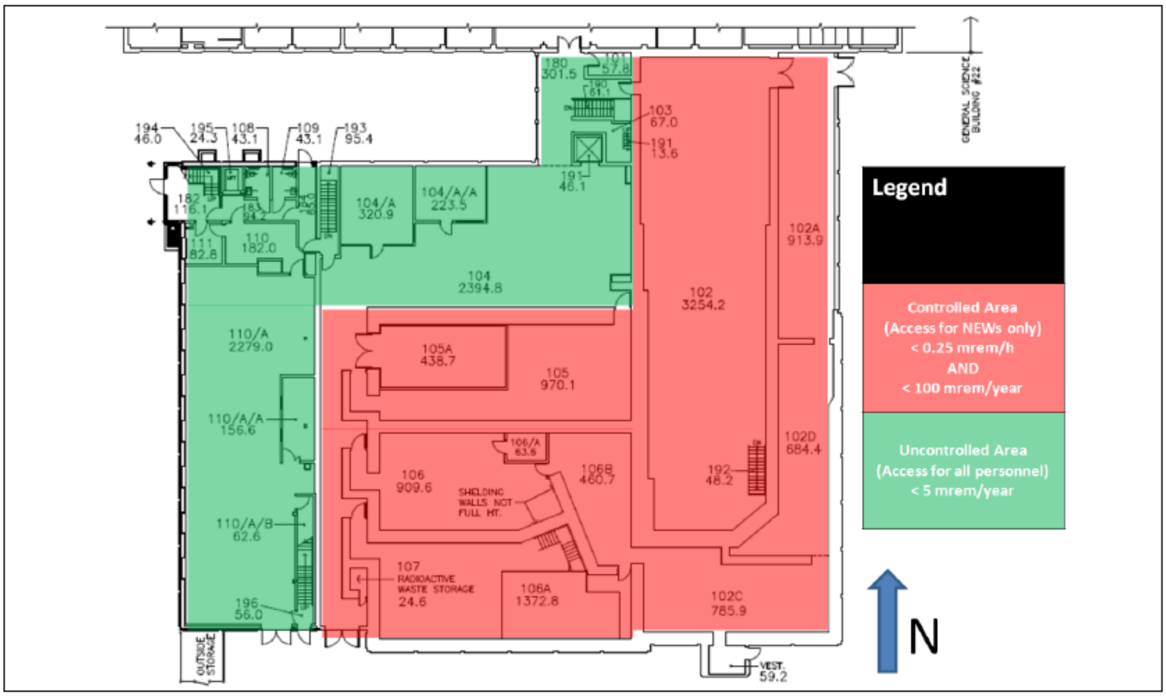

FIG. 2.1. Existing ground level floor of McMaster University tandem accelerator building, with exposure rate zones shown.

- The design basis flasks for receipt of specimens from off-site are not yet determined (although several flask configurations are expected).
  - Flasks will be brought to the receipt cell on a forklift.
  - The flask transit path is from the parking lot south of the TAB, northward in the corridor.
  - The design basis specimen is a segment of Zircaloy 4 CANDU reactor pressure tube, maximum length of 50 cm, nominal diameter of 104 mm, a maximum source (i.e.,

Zircaloy) weight of 10 kg, and maximum additional weight from non-Zircaloy items, such as inner packaging, of 10 kg, for a total design basis specimen weight of 20 kg.

- The radiological source term is based on initial material composed of Zircaloy 4, assumed to be 98.2 weight per cent Zr-94, 1.8 weight per cent tin, with a cobalt (Co-59) content of 20 parts per million by weight, irradiated in a flux of 1E+14 neutrons $cm^{-2}\cdot sec$, for a period long enough to be at saturation with Zr-95 and its decay products Nb-95m and Nb-95, with Co-60 also at saturation, followed by a post-irradiation cooling time of 3 years.
- No actinides are present in the specimens, except as incidental trace contamination.
- The nominal shielding performance requirement is that allowable dose rates shall be <0.25 mrem/hour (2.5 $\mu Sv\cdot h^{-1}$) in areas restricted to occupancy by qualified radiation workers, and <5 mrem/year (50 $\mu Sv\cdot y^{-1}$) in unrestricted areas, as designated in Fig. 2.1.
- The sample receipt and examination throughput rate is 1 per week, based on five shifts per week.

3. SPACE CONSIDERATIONS

At the project inception, it was apparent from informal and qualitative considerations, along with order-of-magnitude cost estimates, that the only realistic option for locating the PIE facility was within the existing TAB. A green-field location was deemed more expensive (for land acquisition). Both a green-field location and a campus location not presently associated with the MNR were considered more expensive and time consuming to license, whereas zones within the TAB are already licensed and operated as radiological areas. The space available for construction of the suite of cells, previously shown in plan view in Fig. 1.1, is designated room 105, and is 60 feet (18.3 m) wide by 24 feet (7.2 m) deep by approximately 20 feet (6.1 m) tall. The existing side walls are 3–5 feet (0.9–1.5 m) thick normal density (approximately 2.3 $g\cdot cm^{-3}$) concrete. The areas south and east of the existing side walls are not accessible for this project. The area north of the existing side wall is not accessible for routine operations and maintenance, but the existing doorway in the northeast corner is available as an emergency personnel exit. The area west of the existing side wall is an 8-foot wide corridor connecting directly to an outdoor receiving area. The corridor is periodically available to bring shielded casks (flasks) containing irradiated specimens from the outdoor receiving area to the [new] transfer port in the existing west wall of room 105. Forklifts will be used for cask movements. The existing doorway between the corridor and room 105 will be relocated.

The room 105 floor is concrete slab-on-grade. The floor will be evaluated during detailed design to confirm loading capacity and vibration response; necessary modifications will be determined.

The overhead space in room 105 is more than necessary for the new cells. The existing bridge crane will be evaluated and modified or replaced as necessary. No modifications to the room 105 ceiling are planned at this time.

4. DESIGN CONCEPT

The design concept is comprised of a suite of six steel-, or steel and concrete-walled hot cells and an adjacent enclosed space for electron microscopy, plus ancillary spaces and equipment for sample handling, waste management, equipment maintenance and transfers, and heating, ventilation, and air conditioning (HVAC) equipment, all to be installed and operated within the existing footprint of room 105 in the Tandem Accelerator Building at McMaster University. Isometric views of the general arrangement of cells and support spaces in room 105 are shown in Figs 4.1–4.2.

The six cells are:

- The receipt, shipping, and machining cell, in which:

- Specimens are received, in shielded shipment and transfer flasks, from off site.
- Specimens are removed from any packaging internal to the flask that was needed for shipment.
- Unpackaged specimens are visually examined.
- Specimens are machined (with in-cell equipment including a cut-off saw, a band saw, and a three-way [i.e., mill, drill press, and lathe combination] machine) into smaller samples as required for subsequent destructive PIE.
- Unused segments of the original specimens are repackaged as required and loaded into a shielded shipment flask for return to the specimen originator.

- The waste management cell, in which radioactive wastes generated in the PIE facility are packaged and characterized as required for subsequent storage, transport, and disposal as directed by the University.
- The mechanical test cell, in which mechanical test apparatus, such as tensile strength racks, are installed and used.
- The microscopy sample preparation cell, in which equipment used to prepare samples for light or electron microscopy, such as polishing wheels or sputter coaters, are installed and used.
- The light microscopy cell, in which light-based microscopy equipment is installed and used.
- The Support Cell, in which temporary and non-routine tests and test in apparatus can be deployed, or active equipment can be repaired and maintained.

Other features of the PIE suite in room 105 include:

- The sample transfer glovebox (off-the-shelf design), connected to the support cell, from which microscopy samples, or samples for laboratory analyses performed elsewhere, or miscellaneous small contaminated items, can be transferred. The principal transfer routes out of the sample transfer glovebox are either into the pneumatic transfer system (with connections to the electron microscopy annex, or into a shielded transfer "pig" for manual transfer as needed.
- The electron microscopy annex, which houses the scanning electron microscope/focused ion beam (SEM/FIB) and the transmission electron microscope (TEM). The electron microscopy annex also houses a small shielded glovebox (off the shelf design) for receiving microscopy samples from the sample preparation cell (via the pneumatic transfer system) or the sample transfer glovebox (via manually transferred pigs).
- Isolated foundation(s) for the SEM and TEM that will provide vibration free mounting recommended for instrument use.
- The sample storage archives, which are shielded spaces adjacent to the electron microscopy annex, dedicated to shielded retrievable storage of previously examined samples.
- A pneumatic transfer system, connecting the PIE cells to the electron microscopy annex.
- An isolation room, which continuously spans the "back" (i.e., the north) side of the PIE cells (except the receipt, shipping, and machining cell), and provides a shielded (but potentially contaminated) maintenance and repair area, and a transfer corridor, in which personnel can perform operations and maintenance activities.

Operations and maintenance approach: the operations approach is that any radioactive material with a contact dose rate >10 $mrem \cdot h^{-1}$ (0.1 $mSv \cdot h^{-1}$) will be exclusively handled remotely, regardless of the duration of material handling operations. Hands-on operations with materials having dose rates <10 $mrem \cdot h^{-1}$ (0.1 $mSv \cdot h^{-1}$) will be evaluated during preliminary design, with consideration given for brief or infrequent operations. Contamination confinement will be conducted in accordance with established University procedures. Design provisions will be made to ensure temporary shielding and contamination confinement during material transfers.

The principal equipment for in-cell material handling is a pair of through-the-wall master-slave manipulators at each cell window. The manipulator model number(s) are not yet determined. However, sealed thru-tube models will not be required, since the expected specimens do not include irradiated fuel. Manipulators are augmented by in-cell hoists where required to lift components that exceed the lifting capacity of the manipulators. Manipulators cannot be installed in the north end of the receipt cell, since there is not room for an operator to stand nor for manipulator removal. Consequently, a robot arm will be provided for material handling in that region.

The preferred maintenance approach for major equipment is to disconnect the failed component in cell, remotely decontaminate (with manipulator-borne wipes and foam-type cleaning agents) to the extent practicable, then remove the component to a suitable location for either hands-on repair or appropriate packaging as waste. This approach allows for prompt replacement of a failed component and minimizes down-time. Accordingly, design provisions are made to remove the largest equipment items from each individual cell, either through doors in the cell backs or removable plugs in the cell roofs.

Only gaseous and solid wastes are generated within the PIE facility. Gaseous wastes are discharged through HEPA filters, into the existing building contaminated off-gas system. Access for testing and replacement of the HEPA filters is via the isolation room.

No significant volumes of liquid wastes are generated within the facility. No liquid-based processes are conducted within the facility. Small (i.e., <2 litres) amounts of liquids such as cutting liquids or decontamination solutions will be absorbed onto suitable media or evaporated to dryness in the waste management cell and packaged there with other solid wastes for subsequent handling and disposal.

Health physics instrumentation (personnel monitors, air monitors, and area monitors) is included in cost estimates, but specific locations are not yet determined.

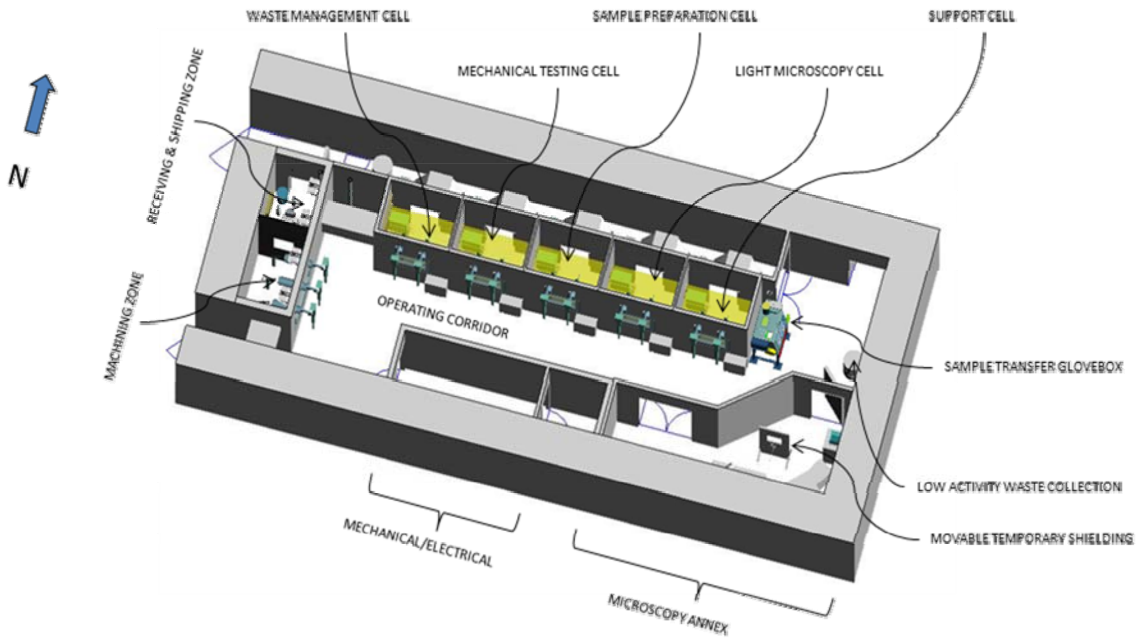

FIG. 4.1. McMaster University PIE cells; overall arrangement.

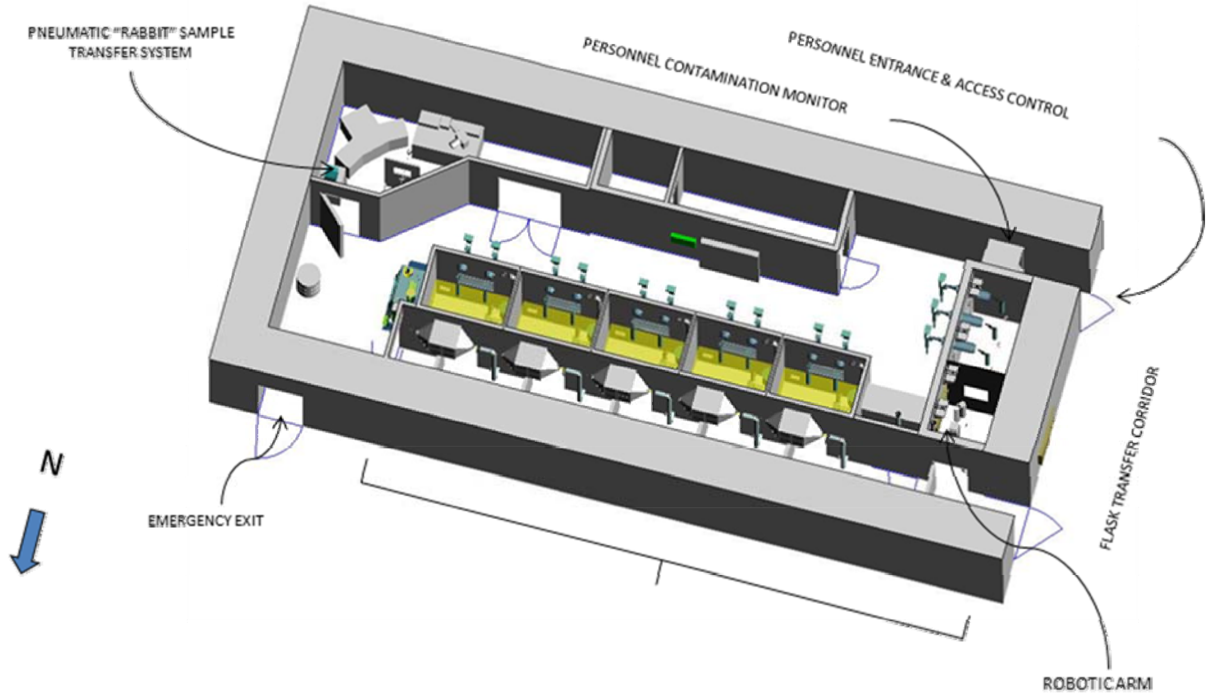

FIG. 4.2. *McMaster University PIE cells, view of rear of cells from within isolation room.*

REFERENCES

[1] CANADIAN NUCLEAR SAFETY COMMISSION, Design Guide for Nuclear Substance Laboratories and Nuclear Medicine Rooms, GD-52 (2010).