IAEA-CN301-165

ISOTOPE HARVESTING PROJECT: FROM WHITE PAPER TO IMPLEMENTATION

DOE-SC Award# DE-SC0021193, Accelerator Improvement Project: Isotope Harvesting at FRIB

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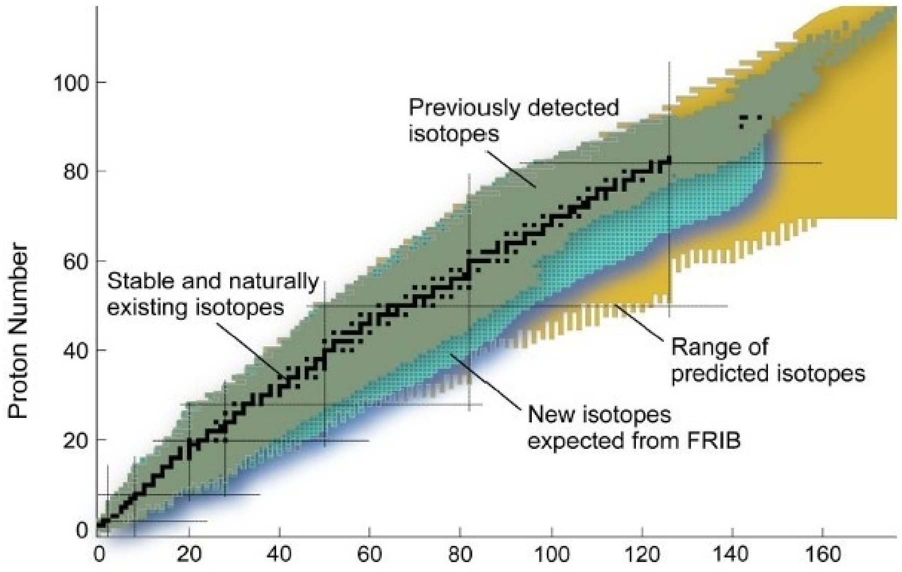
00 OUTLINE

1. Background
2. Introduction
3. Design Basis
4. Conceptual Design and Installations
5. Transition to Operations
6. Summary
7. Acknowledgements

01 FACILITY FOR RARE ISOTOPE BEAMS (FRIB)

- Federally designated user facility for the US DOE-SC
  - Total Project Cost: $730 million, mostly funded by the US DOE- Office of Science
- World leading facility for the production and study of rare isotopes
- Largest university-campus based nuclear science laboratory in the United States
- Enables research opportunities in many areas of rare isotope research
  - Properties of atomic nuclei
  - Nuclear astrophysics
  - Fundamental symmetries
  - **Societal applications**
    - » **Medicine, Energy, material, sciences, national security**
- Program Advisory Committee (PAC 1) of FRIB recommended 34 experiments from 401 individual scientists representing 88 institutions in 25 countries

FRIB offers unique opportunities for experiments with fast, stopped and reaccelerated beams



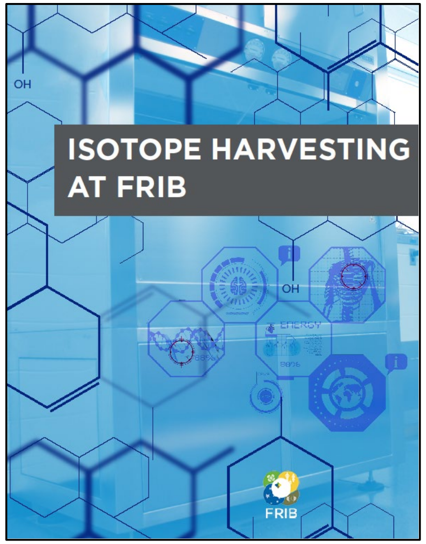
FRIB will provide researchers with more than 1,000 new isotopes never before produced on Earth.

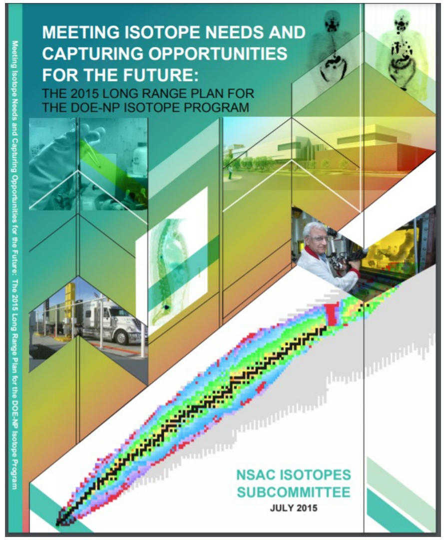
https://wikihost.nscl.msu.edu/outreach/doku.php
https://frib.msu.edu/

01 ISOTOPE HARVESTING PROJECT (IHP)

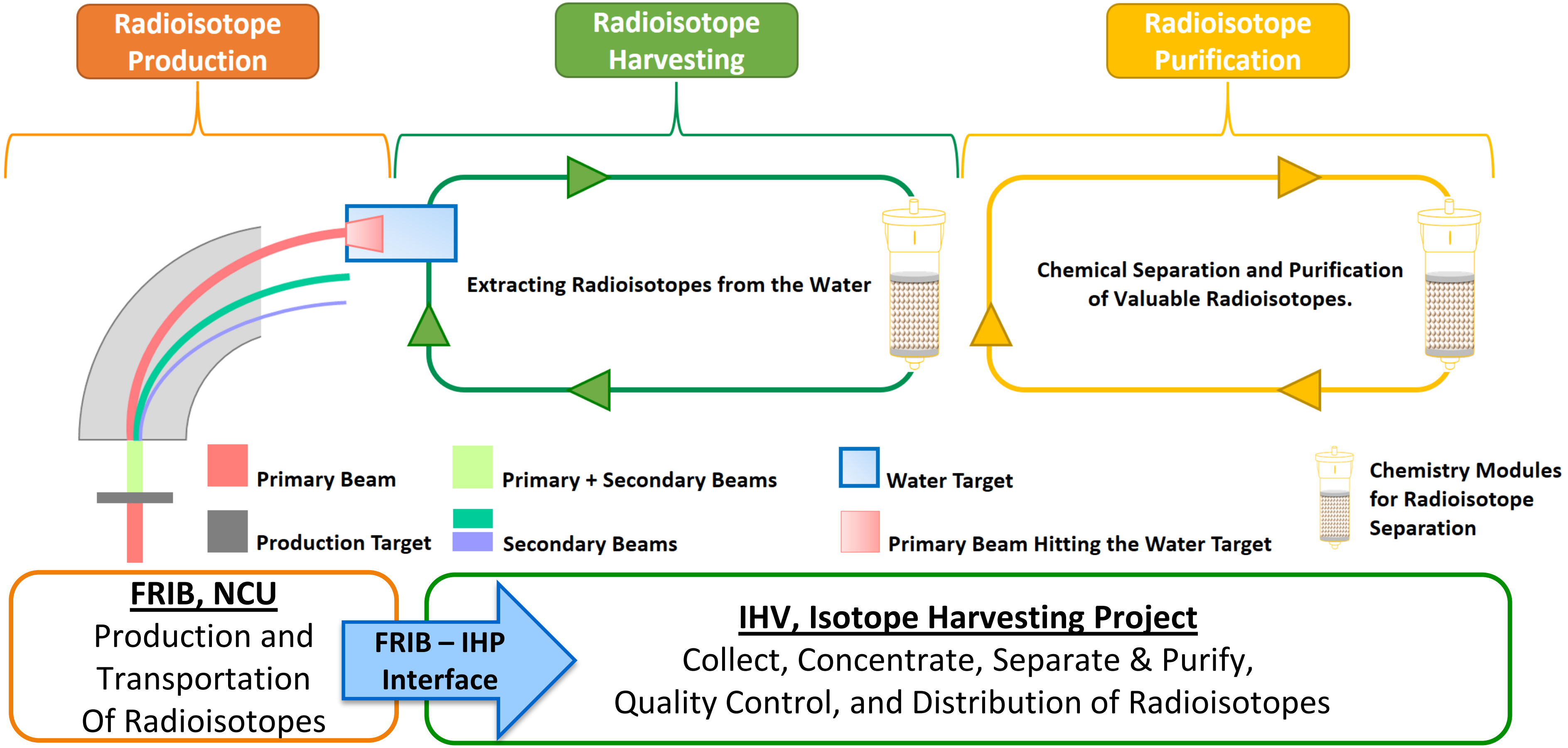
Addresses U.S. Isotope and Workforce Needs

- Upcoming DOE- Isotope Program facility
- Realize the opportunity highlighted in the NSAC-I Long Range Plan
- Capitalize on the university setting to augment the radiochemistry workforce pipeline
- Add value to DOE-SC's investment in FRIB by acting as a secondary user
- Promote the use of radioisotopes in a broadening field of applications
- Hiring practices at MSU and FRIB promote diversity and inclusion
- Being located at a large public university, we can introduce nuclear science to students from all backgrounds and promote diversity and inclusion from an early stage





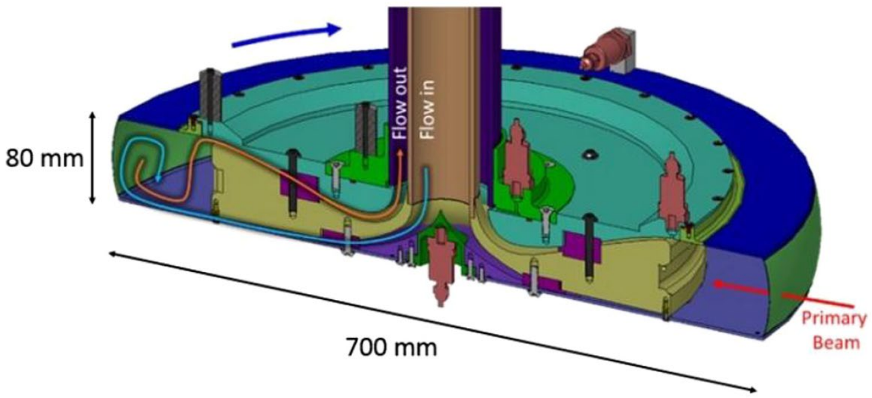
02 IHP OVERVIEW



▪ High Level Requirements

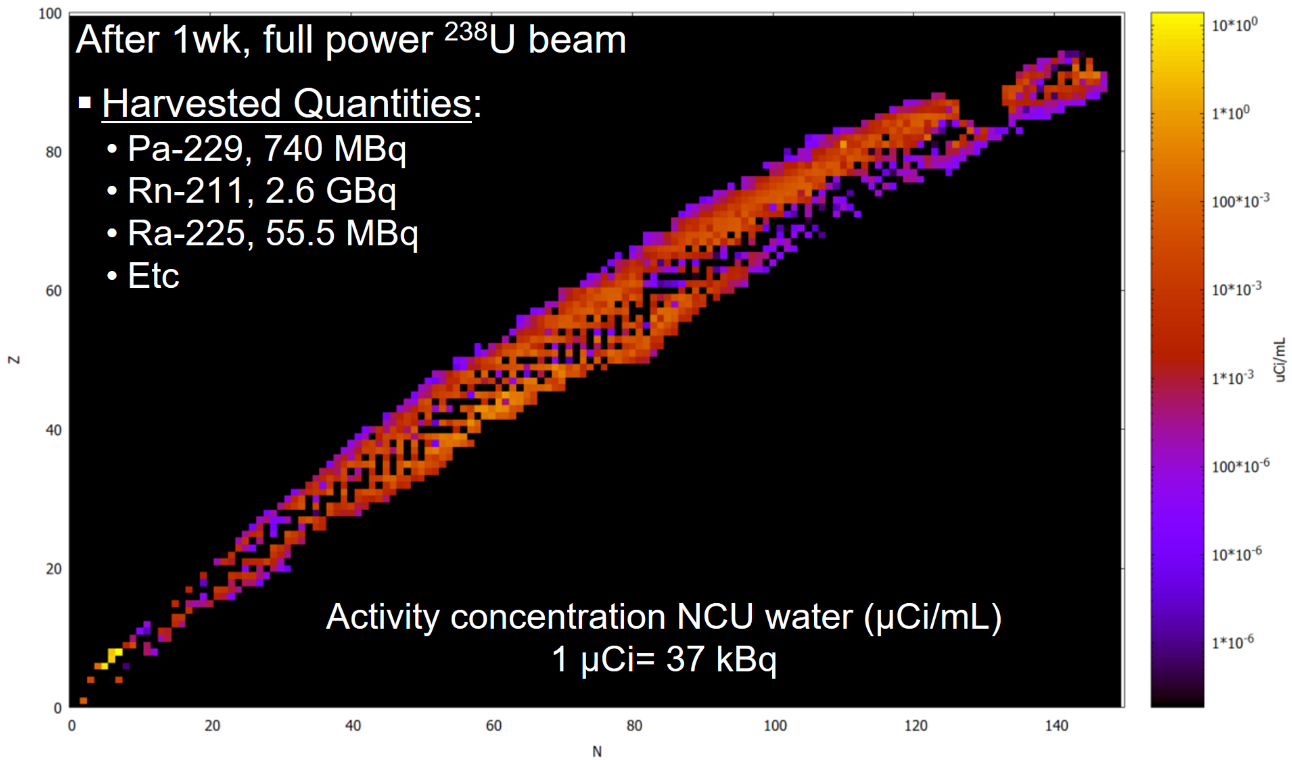
- ➢Radioactive gas and water transportation: Piping and facility modifications
- ➢Radioactive handling equipment and shielding: Radiation shielding, radiation monitoring, QA/ QC, controls

02 BEAM DUMP AND RADIOISOTOPE PRODUCTION



*FRIB Beam Dump

Ti–6Al–4V: low density, high strength, good corrosion resistance, and good fatigue performance
Primary ion beams: From ^{18}O to ^{238}U
Beam power: ~400 kW
Energy: 200MeV/u
Total volume of water: 7000 L



†Beams	^{48}Ca	^{64}Zn	^{78}Kr	^{238}U
†Radioisotopes	$^{47}Ca \rightarrow ^{47}Sc$	$^{62}Zn \rightarrow ^{62}Cu$	$^{77}Kr \rightarrow ^{77}Br$	$^{211}Rn \rightarrow ^{211}At$
†Production Rates of Mother	370.0 GBq/d	118.3 GBq/d	247.9 GBq/hr	15.9 GBq/d

*M. Avilov, A. Aaron, A. Amroussia, et al.; Thermal, mechanical and fluid flow aspects of the high power beam dump for FRIB; Nucl Instrum Methods Phys Res B; 376 (2016) 24–27.
†E. P. Abel, M. Avilov, V. Ayres, et al.; Isotope Harvesting at FRIB: Additional Opportunities for Scientific Discovery; J Phys G: Nucl Part Phys; 46 100501 (2019) 1 – 33.

02 PAST EXPERIENCE

FRIB

Research efforts by our group in the past have demonstrated feasibility for:

- Collection and purification of radioisotopes
  - From flowing water beam dump: ^{47}Ca and ^{62}Zn
  - Gas-phase radioisotope: ^{76}Kr
  - Solid-phase radioisotope: ^{88}Zr
- Simultaneous collection and purification of multiple ions and gases
  - $^{76}Kr + ^{62}Zn + ^{22}Na$
- Radiolysis rates are calculable, and molecular radiolysis products can be managed
  - H_2 pressure and $[H_2O_2]$ are controlled with noble metal catalyst beds. (Does not interfere with harvesting)
- Mass transport of radioisotopes is calculable
  - ^{48}V, ^{51}Cr, ^{47}Ca, ^{76}Kr, ^{77}Kr, etc.

ACS OMEGA
http://pubs.acs.org/journal/acsodf Article

Production, Collection, and Purification of ^{47}Ca for the Generation of ^{47}Sc through Isotope Harvesting at the National Superconducting Cyclotron Laboratory

E. Paige Abel, Katharina Domnanich, Hannah K. Clause, Colton Kalman, Wes Walker, Jennifer A. Shusterman, John Greene, Matthew Gott, and Gregory W. Severin*

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Harvesting ^{62}Zn from an aqueous cocktail at the NSCL†

Katharina A. Domnanich,[ab] Chirag K. Vyas,[ab] E. Paige Abel,[ab] Colton Kalman,[ab] Wesley Walker[ab] and Gregory W. Severin*[ab]

Contents lists available at ScienceDirect
Nuclear Inst. and Methods in Physics Research B
journal homepage: www.elsevier.com/locate/nimb
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Durability test of a flowing-water target for isotope harvesting

E. Paige Abel[a,b], Katharina Domnanich[a,b], Colton Kalman[b], Wes Walker[b], Jonathan W. Engle[c,d], Todd E. Barnhart[c], Greg Severin[a,b,*]

Contents lists available at ScienceDirect
Applied Radiation and Isotopes
journal homepage: http://www.elsevier.com/locate/apradiso
ELSEVIER

Radiolysis and radionuclide production in a flowing-water target during fast $^{40}Ca^{20+}$ irradiation.

E. Paige Abel[1], Hannah K. Clause[1], Gregory W. Severin*

OPEN
Check for updates

Harvesting krypton isotopes from the off-gas of an irradiated water target to generate ^{76}Br and ^{77}Br

Hannah K. Clause[1,2], Katharina A. Domnanich[1,2], Chloe Kleinfeldt[1,2], Morgan Kalman[1,2], Wesley Walker[1,2], Chirag Vyas[1,2], E. Paige Abel[1,2] & Gregory W. Severin[1,2]

03 APPROACH TO DESIGNING & CONSTRUCTION

Design is driven by safety

- Main hazards
  - ➢ High radiation dose rates
  - ➢ Large quantities of dispersible radioactivity

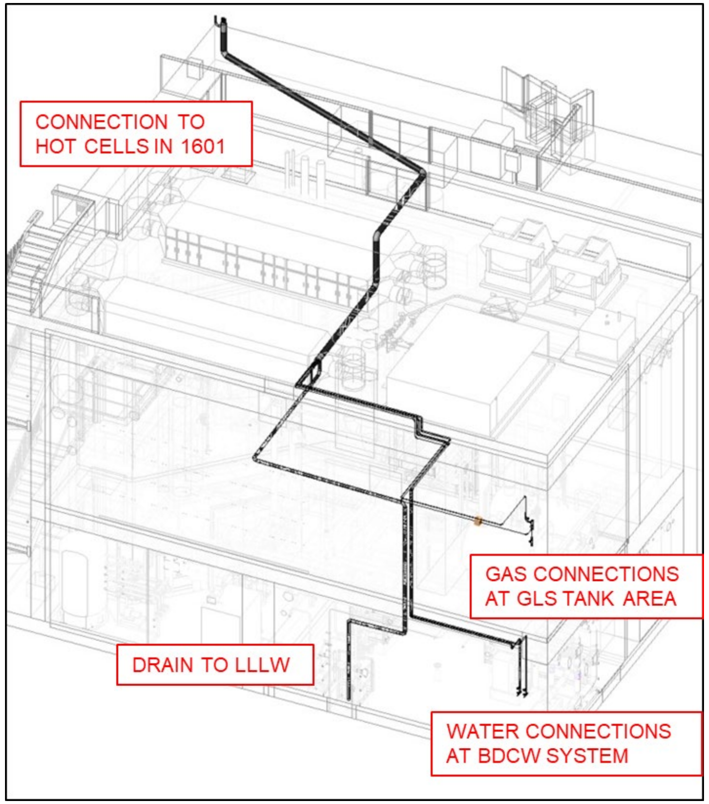
Main mitigations

- Shielding
- Layered Containment
- Radiation Detection and Sensors

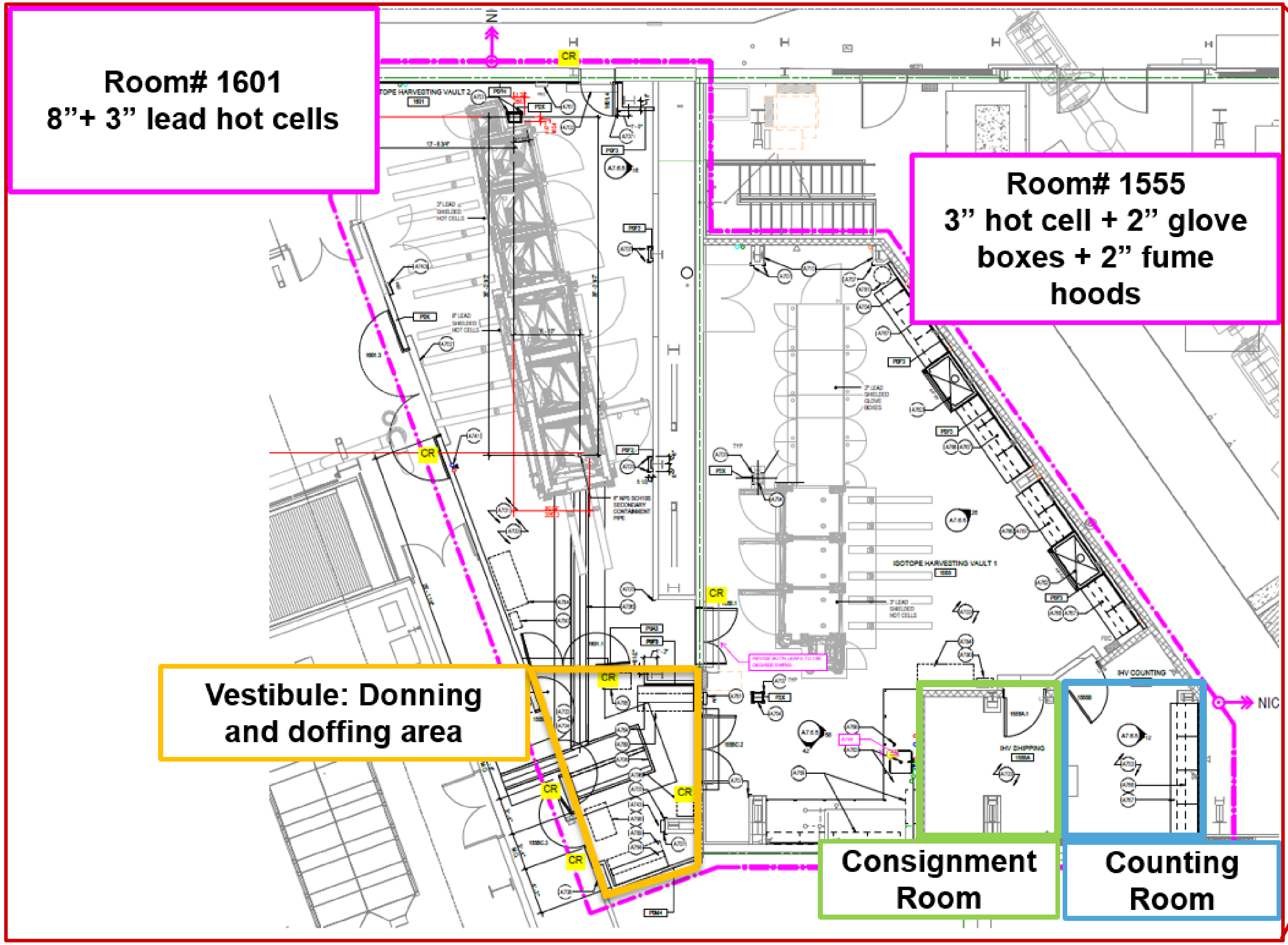
Construction aims providing

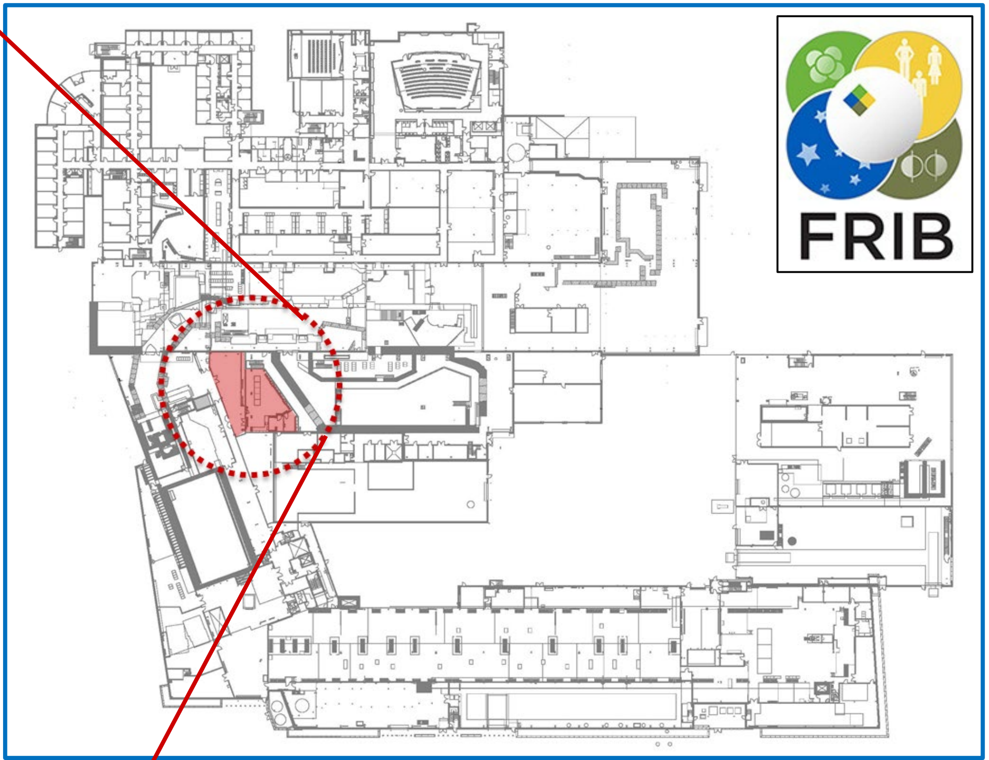
- Safe access to irradiated water and off-gas
- Equipment for radiochemical processing
- Instrumentation to assay product quality

Radioactive Water and Gas Piping from NCU to IHV



04 ISOTOPE HARVESTING VAULT (IHV)





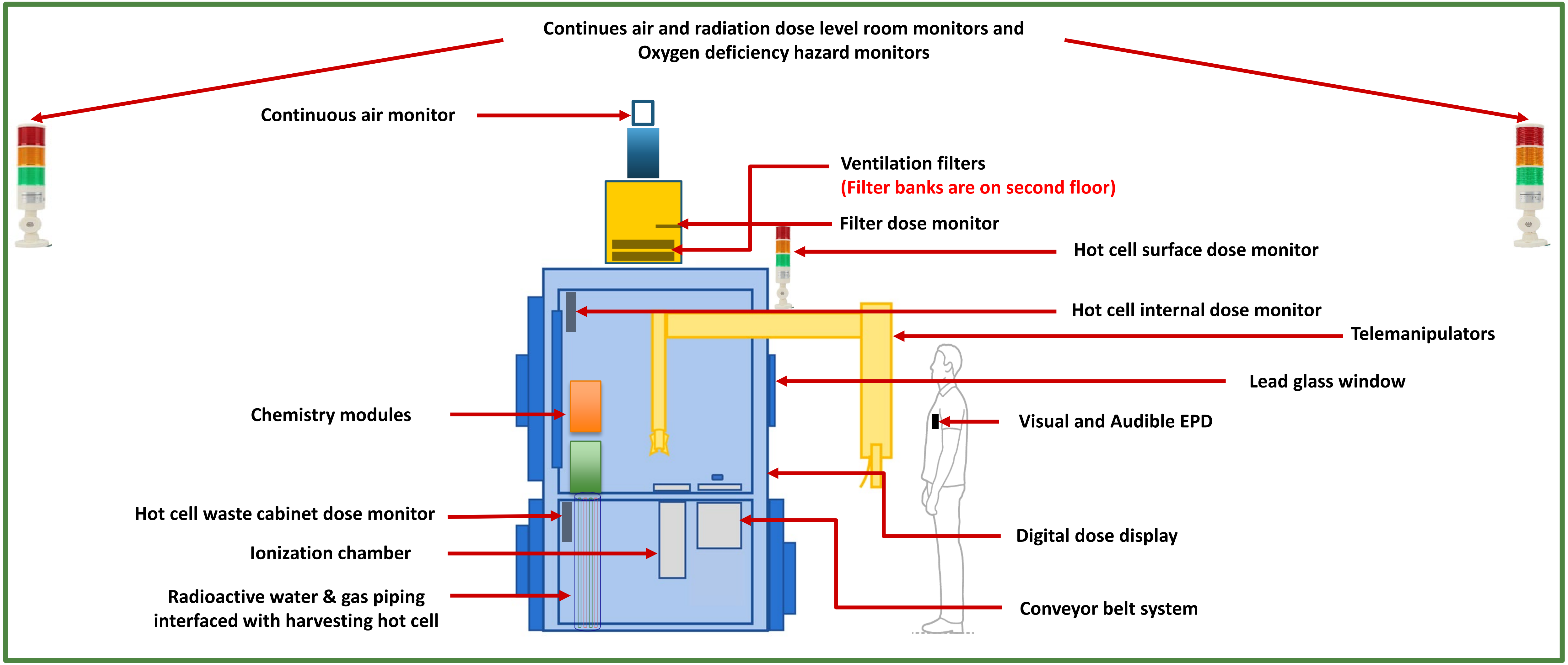
International Conference on Accelerators for Research and Sustainable Development #Accelerators2022 23–27 May 2022 IAEA, Vienna, Austria

03 HAZARDS, SOURCE TERMS, AND MITIGATIONS

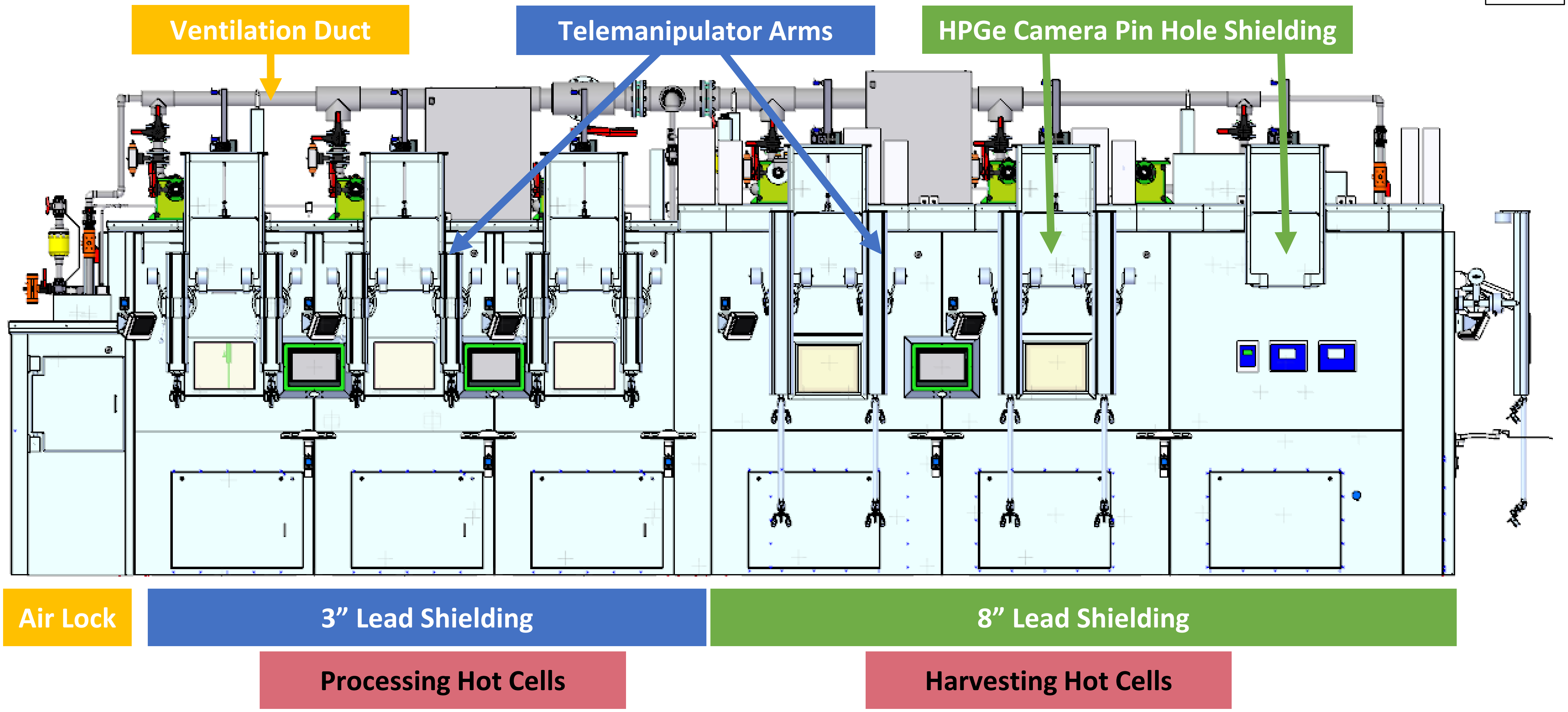
Hazard	*Source Term	Active/ Administrative Controls	Passive Controls
Direct Radiations from radioactive water	100 µCi/mL to 4.9 Ci (mixed)	- Radiation dose monitors - Door interlocks - Gas and water supply valves - Door padlocks - Dosimetry and Telemetry	- 4.5” lead equivalent shielding - 8” lead shielded hot cells - 3” lead shielded hot cells - 2” lead glove box - 2” lead shielded fume hoods, 3” lead shielded floor port transport carts, 3” lead shielded carts and 3” lead/ Tungsten shielded pigs
Radioactive water leak from pipelines	100 µCi/mL (mixed)	- Leak detection system (leak detection tape/ level sensor Radioactive Water Drain Capture Tank in NCU) - Water supply valves interlocked with leak detection system (automated and manual)	- Primary piping (ASME B 31.3) - Secondary piping (ASME B 31.3) - Tertiary containment NCU/ Piping trench - Radioactive water drain capture tank
Radioactive water leak within the hot cell	100 µCi/mL (mixed)	- Leak detection system (leak detection tape/ level sensor Radioactive Water Drain Capture Tank in NCU) - Water supply valves interlocked with leak detection system (automated and manual) - Door interlocks and Door padlocks	- Leak tight doors, ISO 10648-2, class 2 - Hot cell containment - Secondary piping (ASME B 31.3) - Radioactive water drain capture tank
Radioactive gas leak from pipelines	3 µCi/mL (mixed)	- Leak detection system (CAM and Radiation detectors in filter stack) - Gas supply valves interlocked with leak detection system (automated and manual)	- Primary piping (ASME B 31.3) - Secondary piping (ASME B 31.3) - Tertiary containment HOG
Radioactive gas leak within the hot cell	900 mCi ^{76}Kr	- Door interlocks and Door padlocks - Gas flow valve interlock (automated and manual) on radiation detection. - Leak detection system (Continuous Air Monitors and Radiation detectors in filter stack) - Gas supply valves interlocked with leak detection system (automated and manual) - Air flow to HOG	- Leak tight doors, ISO 10648-2, class 2 - Nuclear grade carbon and HEPA filters - Tertiary containment HOG
Loss of HOG ventilation	-------------------------	- Leak tight doors, ISO 10648-2, class 2: 8” and 3” lead shielded hot cells and 2” lead shielded glove boxes - Automated hot cell and glove box isolation in event of HOG failure, local alarms - HOG failure detected by pressure monitoring in the hot cells and glove boxes	--
Oxygen deficiency hazard	<19.5% of O_2	- Oxygen deficiency hazard monitors	--

***Source term calculations are based on one week full power (400 kW) ^{238}U beam irradiation**

04 HARVESTING HOT CELL CONCEPTUAL LAYOUT



04 DESIGNING PHASE OF HOT CELLS COMPLETED



04 RADIATION MONITORING AND QA/ QC

Radiation Monitoring Devices

- Radiation Monitoring Station
- Telemetry
- Portal Monitor
- Swab Counting System
- Area Radiation Monitors
- Continuous Air Monitoring System
- Radiation Survey Meters
- Hand and Foot Monitors
- Electronic Personal Dosimeter

QA/ QC Instruments

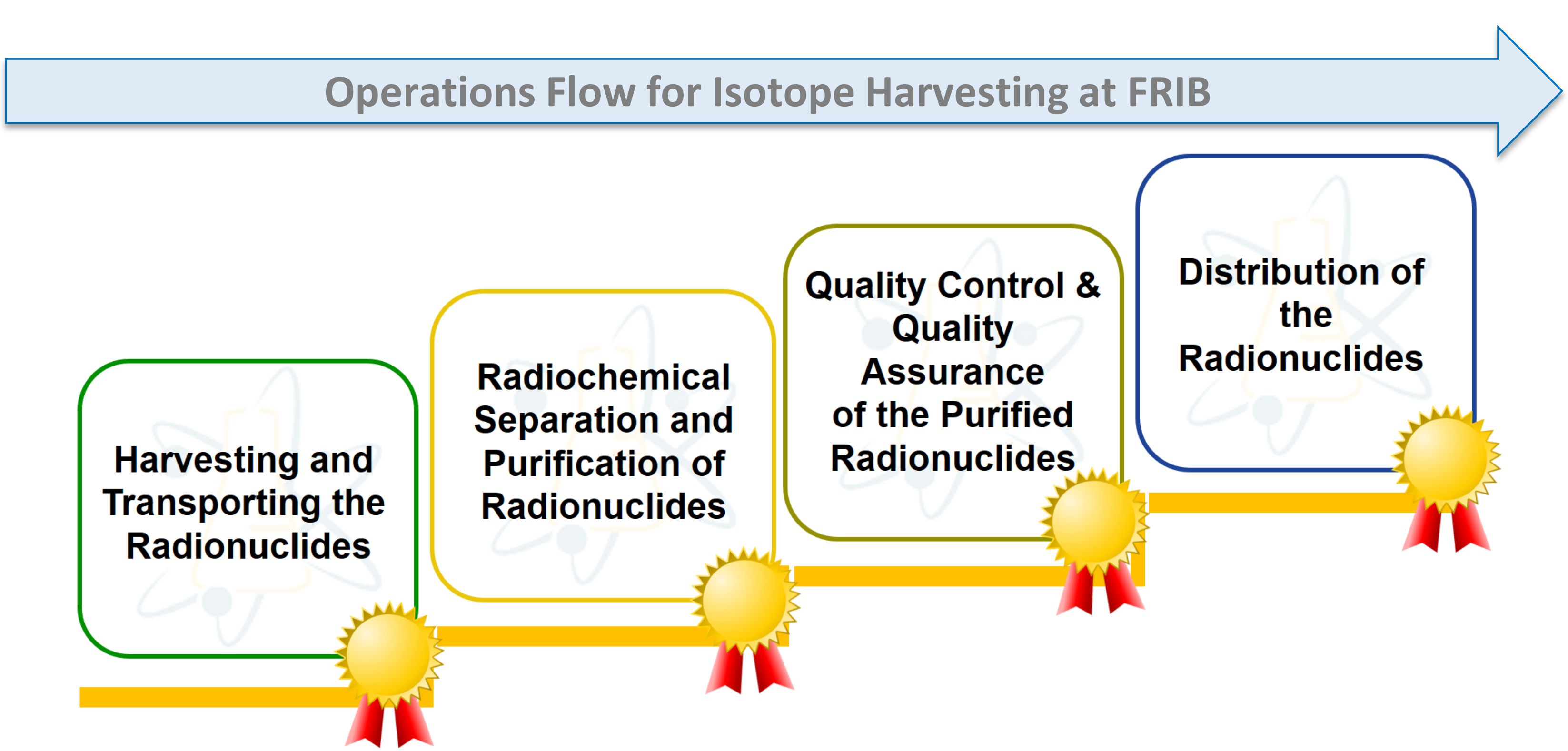
- ICP-OES/ MS
- HPGe
- Portable HPGe
- Liquid scintillation counter
- Gamma counter
- Phosphor imager
- Radio-TLC with detector flexibility
- HPLC with DAD and NaI detectors
- UV-Vis-NIR spectrophotometer
- Alpha spectrometer
- Dose calibrator
- Total organic carbon analyzer

05 DETAILS ON TRANSITIONING TO OPERATIONS

FRIB

- **Transition to operations will begin in 2023**
  - **2022**
    - » Develop budget and schedule and submit proposal for operations funding
    - » Prepare HR for hiring
    - » Form an advisory committee for operations to advise through transition
    - » Form an IHP, FRIB (internal stakeholder) committee for routine review of operations
  - **2023**
    - » Orientation and training for staff
    - » Hire technicians
    - » Establish safety protocols and equipment SOPs
    - » Obtain FRIB RSC approval and NRC license amendments for initial operations
    - » Establish procedures for transferring samples from IHP, FRIB to offsite labs
      - Bridge MSU RSC – FRIB RSC – NRC req's- DOT req's
    - » Establish record-keeping practices for products per NIDC protocols
    - » Acquire samples for R&D program during FRIB ramp up
  - **2024**
    - » Implement developed procedures from R&D effort into production
    - » Establish QA/QC protocols for products
    - » Send test batches through NIDC and use feedback from test batches to improve products
  - **2025**
    - » Maintain mission readiness with feedback DOE-IP/ NIDC / and R&D effort

05 PROJECT DELIVERABLES



Demand of the Radionuclides

- Coordinating with DOE/ NIDC for collecting the demands for the needed radionuclides.
- Understanding needs and application
- Develop and follow the SOP for production of a specific radionuclide
- Strict would be followed to deliver the produced radionuclides.

06 SUMMARY

Procurement & Installation

- ✓ Radiation Safety
- ✓ Hot Cells
- ✓ Glove Box
- ✓ Chemistry materials
- ✓ QC and QA Instrumentation
- ✓ Waste Management

Testing and Validation of the Equipment

- ✓ Factory Acceptance Test
- ✓ Capability Test
- ✓ Instrument Validation
- ✓ Controls
- ✓ Data Acquisition
- ✓ Site Acceptance Test

Protocol Standardization

- ✓ Radiation Safety
- ✓ Isotope Harvesting
- ✓ Radiochemical Processing
- ✓ QA and QC
- ✓ Radionuclide Distribution
- ✓ Waste Management

We are committed to:

- Retaining mission readiness while increasing harvesting capabilities and capacity
- Augment our ability to meet the needs of the DOE Isotope Program
- Delivering a world-class Isotope Harvesting laboratory
- Training the future radiochemistry workforce

07 ACKNOWLEDGEMENT

FRIB

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Thank You


FRIB


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