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Development of Remote Monitoring System for Dry-Storage of Aluminum-Clad SNF (Instrumented Lid Project)

Idaho National Laboratory

Outline

- Background on the issues facing extended dry storage of aluminum-clad spent nuclear fuel (ASNF)
- Brief look at previous efforts at INL to implement in-situ monitoring of ASNF
- Current activities to develop a remote canister monitoring system (RCMS)
  - Three approaches identified and feasibility studies ongoing
  - Feasibility studies in collaboration with Idaho State University (ISU) and Westinghouse (WH)
- FY20 activities to develop an RCMS
- Ongoing FY21 activities

Background

Need for RCMS

- Need for a more complete understanding of ASNF behavior
  - Provides technical basis for continued storage of this material
  - Critical to safe, extended dry storage in current and future configurations
  - Will inform future transportation, conditioning, and disposal of ASNF
- June 2017 DOE SNFWG identified five knowledge gaps
  - DOE/ID RPT-1575 "Aluminum-Clad Spent Nuclear Fuel: Technical Consideration and Challenges for Extended (>50 Years) Dry Storage"

Five knowledge gaps and technical needs for extended storage of ASNF

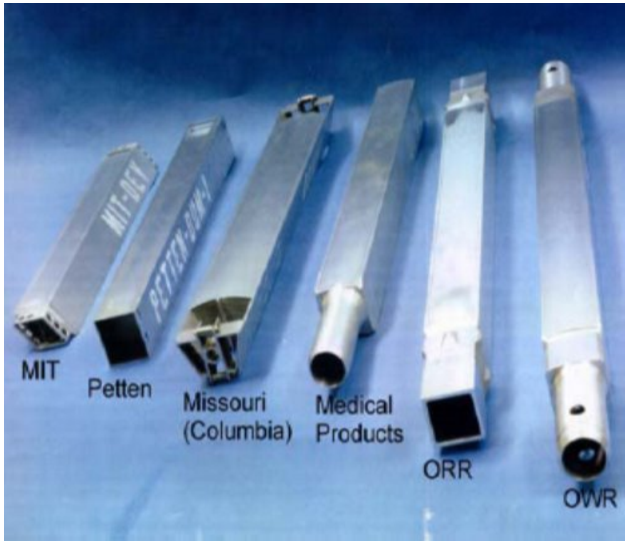
1. Oxyhydroxide layers behavior and chemistry
   - Need to understand the oxyhydroxide layers that form on ASNF
2. Radiolytic gas generation
   - Need to improve the resolution of radiolytic gas generation data for ASNF oxyhydroxide layers
3. Effect of combined phenomena
   - Need to understand the combined effect of episodic breathing and radiolytic generation of corrosive gases in sealed and vented systems
4. Performance of ASNF in dry storage systems
5. Effect of high-temperature drying (i.e., greater than 100°C) on the chemistry and behavior of oxyhydroxide layers

Importance of in-situ monitoring

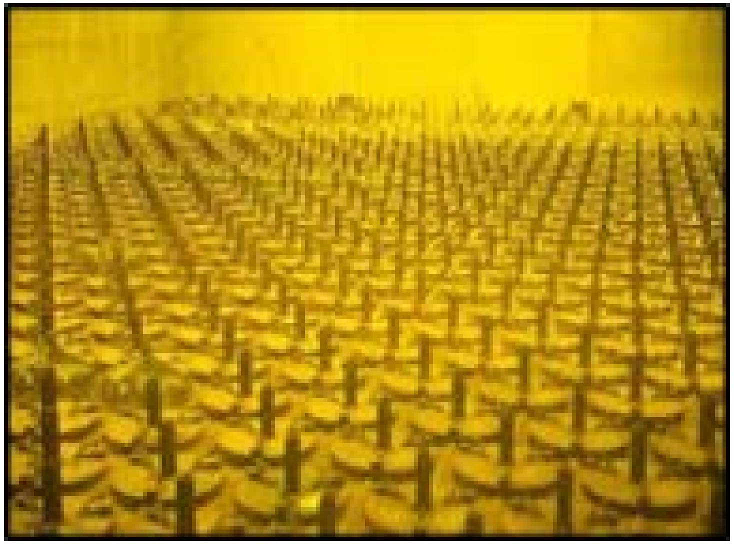
- In-situ monitoring capability can support addressing
  - Radiolytic gas generation
  - Effect of combined phenomena
  - Performance of ASNF in dry storage systems
- In-situ monitoring of ASNF performance provides the opportunity to:
  - Evaluate the appropriate technologies for monitoring
  - Collect canister environment conditions as soon as possible
  - Verify and validate lab-scale results and analytic/simulation modeling approaches
  - Potentially identify additional dry storage options for ASNF at the INL site
- Key parameters of interest to be monitored by the RCMS:
  - Temperature, relative humidity, hydrogen gas concentration, and radiation environment (dose)

Aluminum-clad Fuel at INL

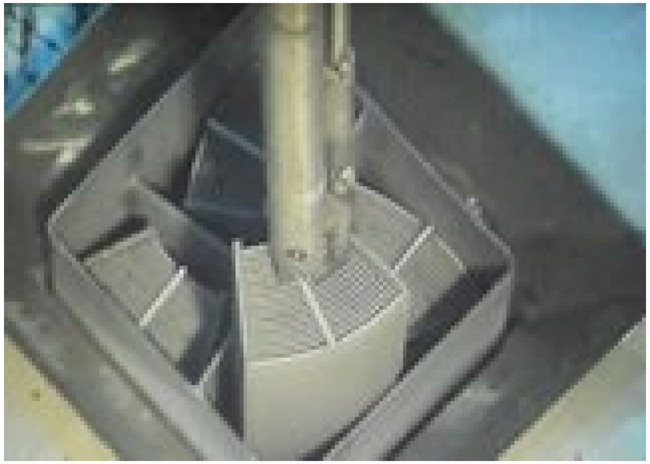
- Various ASNF at INL
- Majority is from the Advanced Test Reactor (ATR)
- ATR fuel placed in baskets for transfer from the pool, dried, and put into dry storage at CPP-603



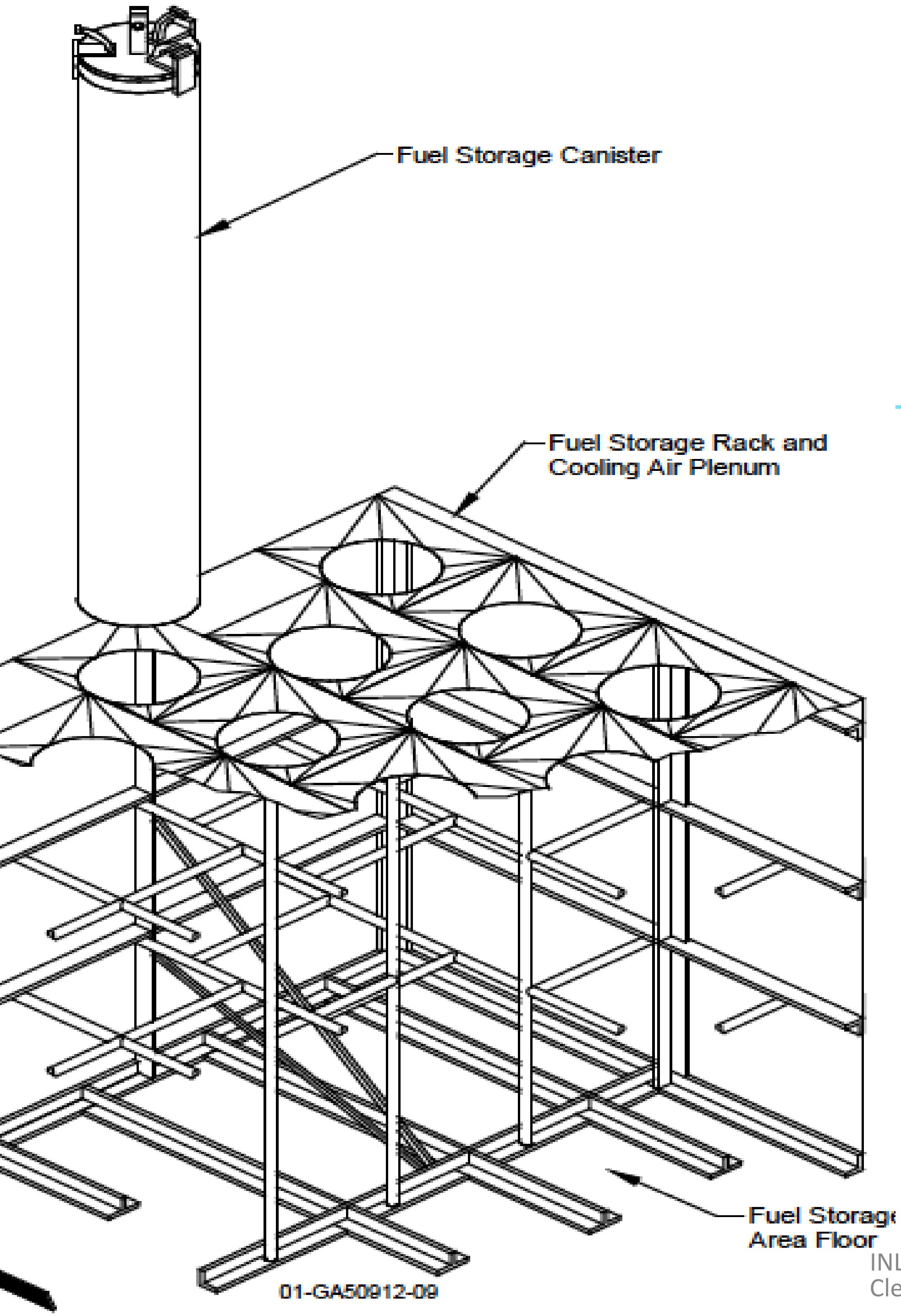
Research reactor fuel elements



CPP-603 Fuel storage area



ATR fuel elements



CPP-603 – Irradiated Fuel Storage Facility

- Commissioned 1974, designed to store Fort St. Vrain (FSV) SNF
- Canisters suspended in steel framework
- 1/3rd of capacity used for FSV fuel before shipments were stopped
- Remaining spaces used for storage of other SNF (mostly ATR)

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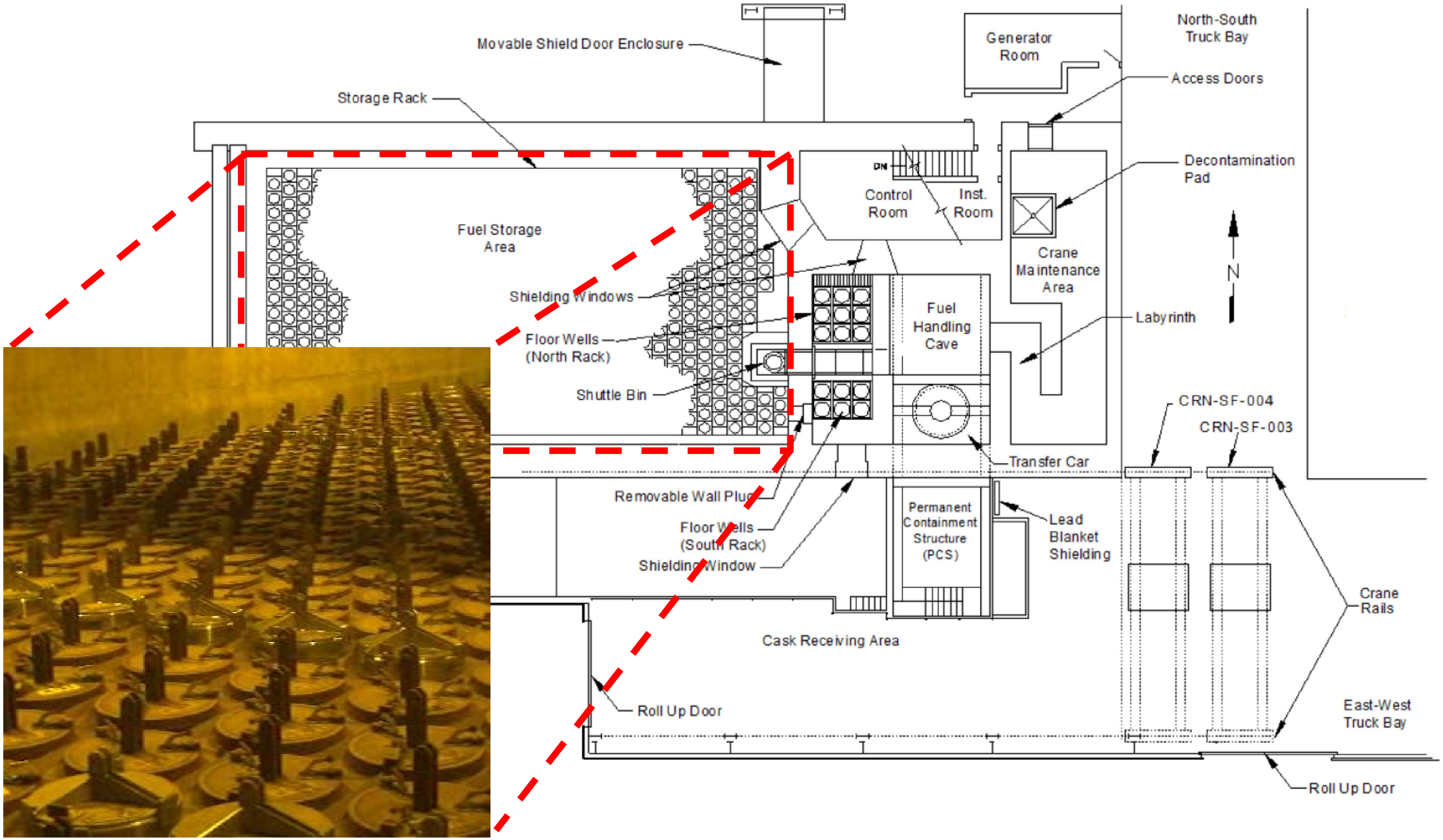
CPP-603 facility layout



Dry storage, CPP-603, at the INL site

CPP-603 Storage Canister

- Nominal lightweight storage canisters used in CPP-603
  - Carbon steel (CS) or stainless steel (SS)
  - 18.0-in. nominal diameter
  - 11-ft nominal length
  - Lid held in place via a clamp (not sealed)
  - Lifting bail for remote handling by the crane, hoist, or manipulator
- Carbon steel canister chosen for the RCMS design activities:
  - Represents the majority of canisters (174 SS vs. 461 CS)
  - Currently being used for loading of ATR fuel in the CPP-603
  - New canister most likely to host the first RCMS prototype

ATR Fuel

- Each assembly is made of 19 curved aluminum-clad uranium aluminide plates
- Highly enriched uranium (93.5 wt %) with nominal loading of 1075 g U235
- For extended storage, the fuel elements are cropped to the plate length and placed inside a fuel bucket/basket
- Once cropped, fuel elements are moved together using the buckets

ATR Loading Configurations

- Various loading configurations used for ASNF in CPP-603
- RCMS targeting configurations for ATR fuel
- ATR fuel constitutes a large component of ASNF in CPP-603
- Continuing ATR operations generates more ASNF
- ATR SNF is expected to be stored at CPP-603

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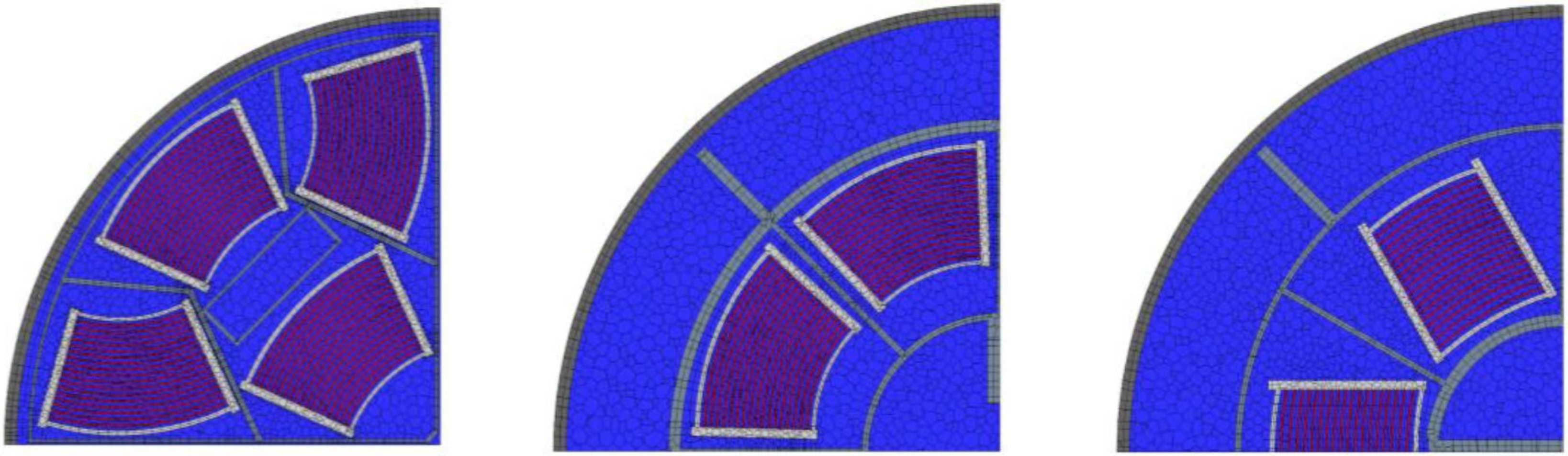
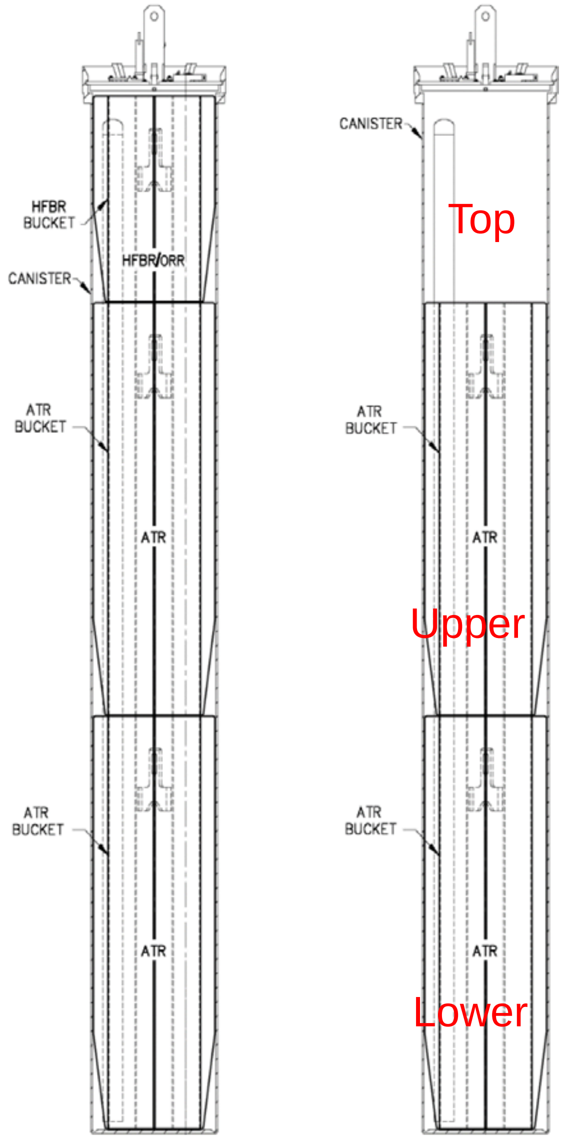
Fuel loading buckets

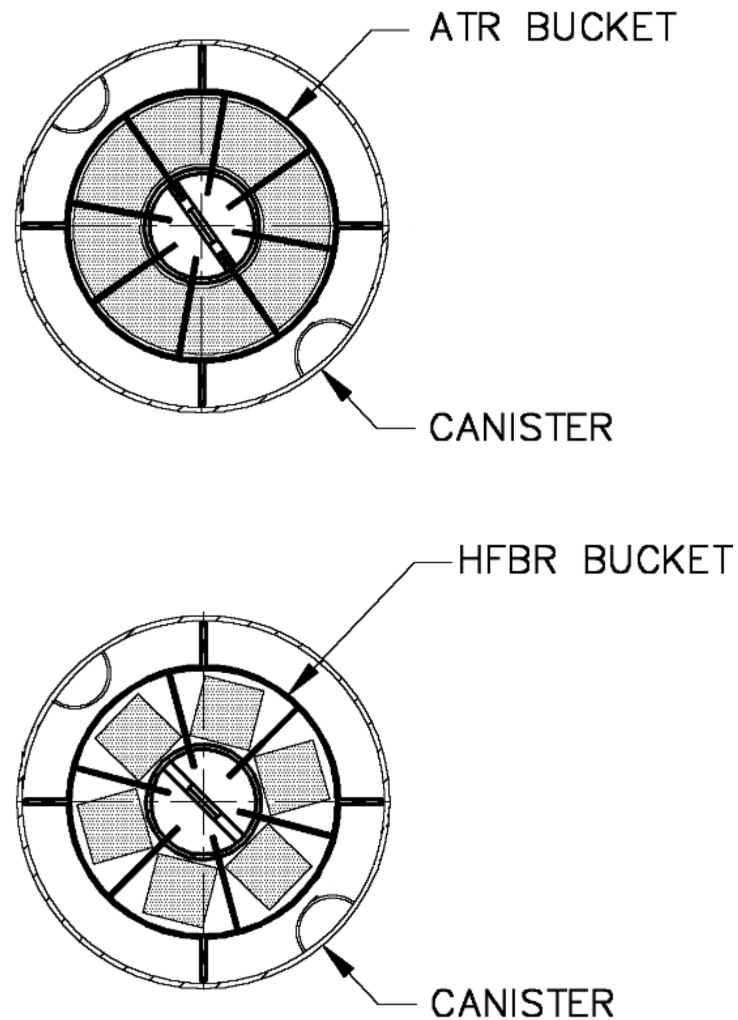
- Nominal contents 3 buckets, (2 ATR buckets and one of HFBR, MURR or MTR)
- ATR bucket ~50” high
  - 6 and 8 position in service
- HFBR bucket ~ 28” high
  - 6 element positions
- Constructed of 304L SS, not used in wet storage, only transfer and dry storage



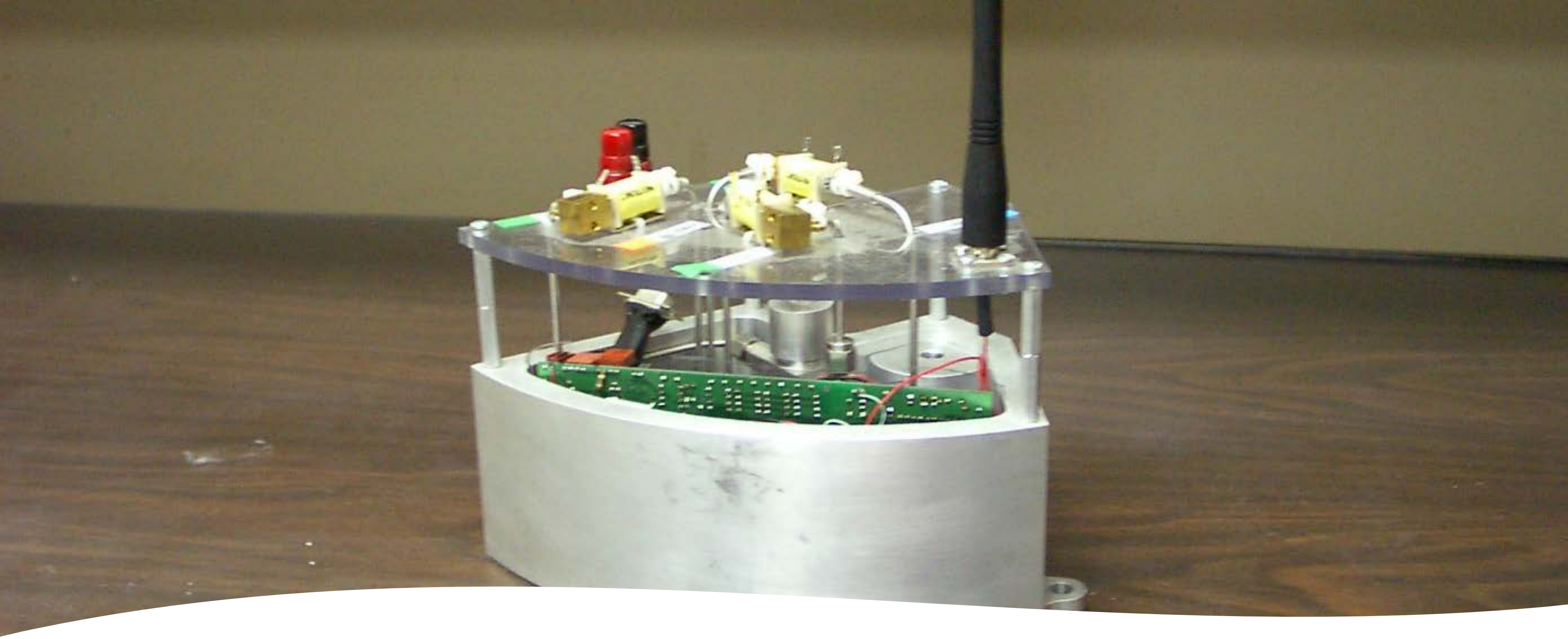
ATR4 Bucket   ATR8 Bucket   HFBR Bucket

ATR loading configurations



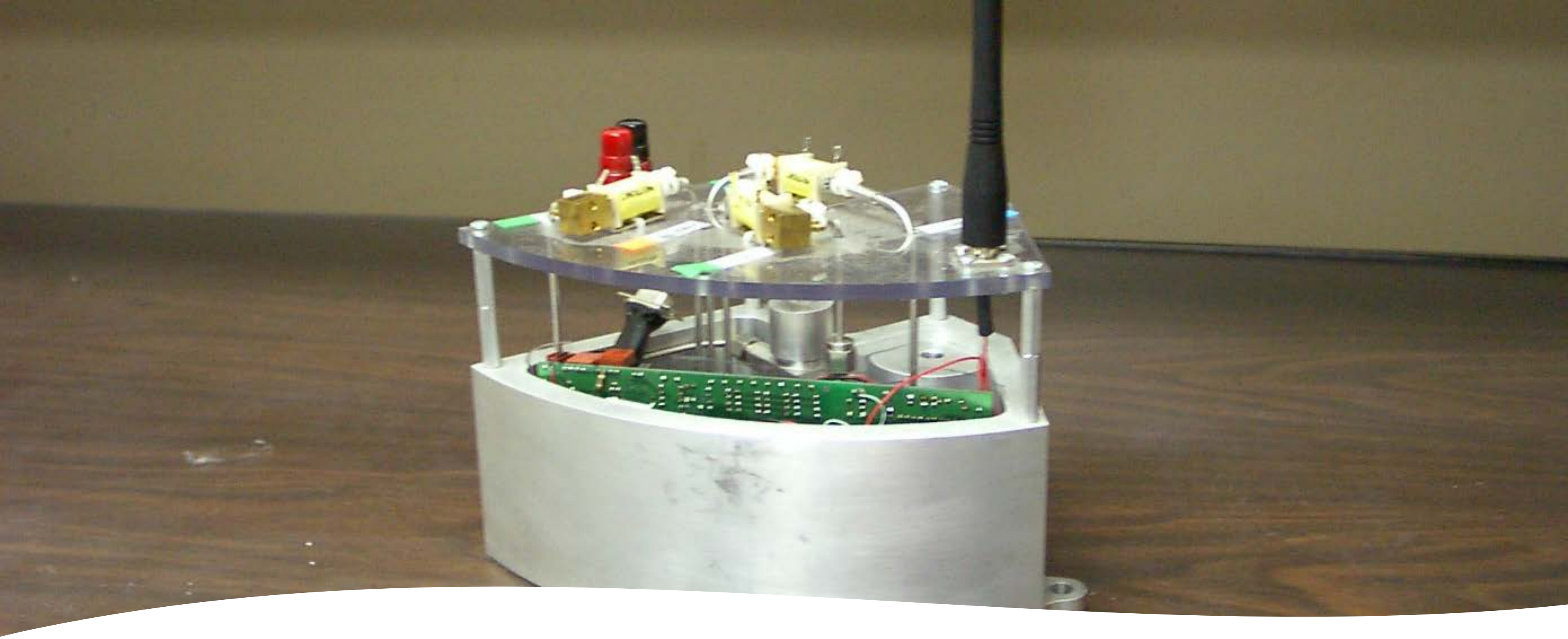


Previous efforts at INL



Previous efforts

- In-situ monitoring capability has always been desired
- Prototype was developed between 1999-2001
- Detectors in shielded compartment on canister lid. Penetration in lid to allow gas circulation and direct radiation monitoring
- Focus was corrosion and radiolysis



Integrated sensor system prototype

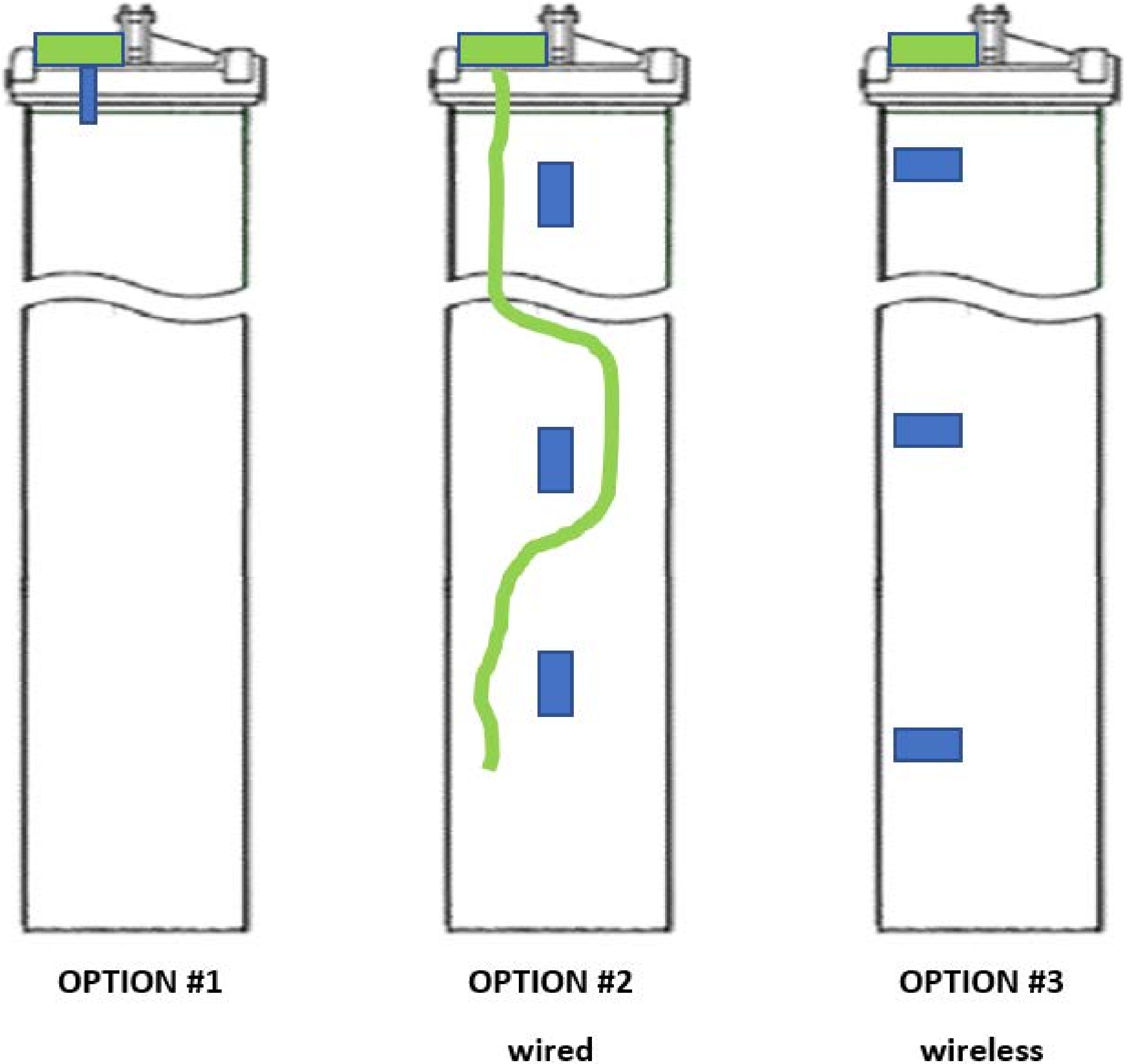
- Intended to measure temperature, hydrogen concentration, and radiation dose
- Designed to use radio frequency to transmit data from inside the fuel storage area
- Shielding to protect batteries and instrumentation from 500 R/hr gamma radiation field
- Actual prototype was not deployed

Current efforts

Three approaches for RCMS development

- Approach #1 – Technology update of 2000s prototype
  - Update components with newer equivalent technologies
  - Allows acquisition of point estimate data
- Approach #2 – Wired solution
  - Requires threading of thermocouples and wired sensors into the canister geometry
  - Allows acquisition of spatial information inside the canister
- Approach #3 – Wireless solution
  - Use passive wireless sensors that will be resident in canister
  - Potential benefits to maintenance and facility operations
  - Allows acquisition of spatial information inside the canister

Three approaches for RCMS development



Scope of feasibility studies

- Selection and procurement of appropriate sensors and key system components
- Separate testing of individual sensors for performance and calibration
- Testing of components under expected environmental conditions
  - Temperature, relative humidity, and hydrogen concentration
  - Component irradiation testing
- Testing of wireless transmission of collected data to data acquisition system

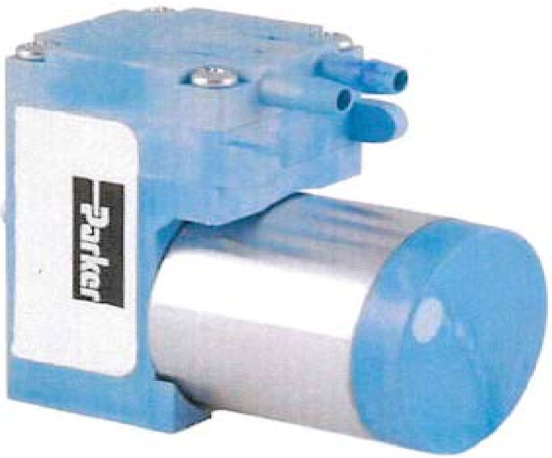
Collaboration with ISU

Several off-the-shelf commercially available components available

Component	FY2000 Prototype	New Prototype
Hydrogen sensor	Figaro TGS2620 Figaro TGS821	Several off-the-shelf options (Figaro, H2scan, N5)
Radiation sensor	Gamma Labs G1300	Several off-the-shelf options (Mirion, Gamma Labs)
Temperature sensor	Digital thermocouple	Several off-the-shelf options (Hioki LR5011, Comet T3611, N5)
Humidity sensor	FSU-2K unit (EMD-2000)	Several off-the-shelf options (Hioki LR5011, Comet T3610, EMD-4000, N5)
Air sample collector	Miniature air pump	Miniature air pump
RF transmitter	RF (450MhZ, 600ft range)	Several off-the-shelf options (N5 has Wi-Fi)
Microprocessor	z80	Several off-the-shelf options (N5 uses Arduino platform)
Onboard memory	128K EEPROM	Several off-the-shelf options (N5 uses Arduino platform)
Software	N/A	Requires code development in-house
Power source	Li-ion batteries	Li-ion batteries

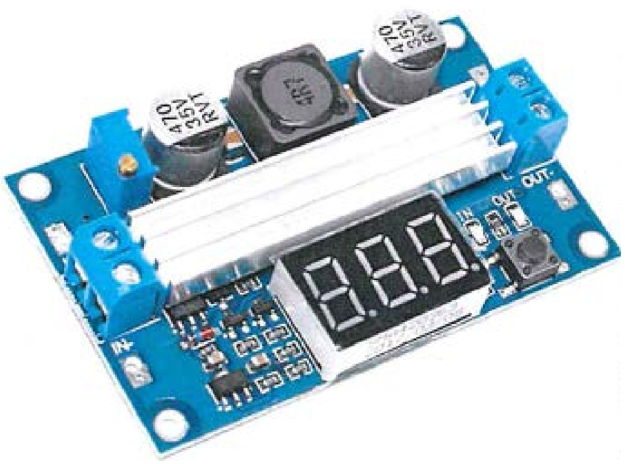
Component selection

N5 digital gas module



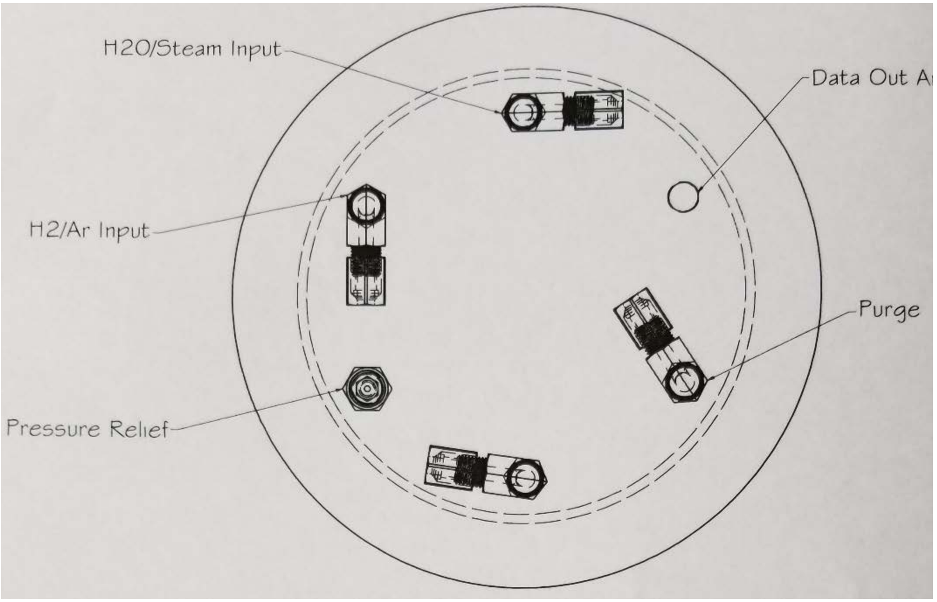
Cole-Palmer miniature air pump

Wide rage of radiation detectors available

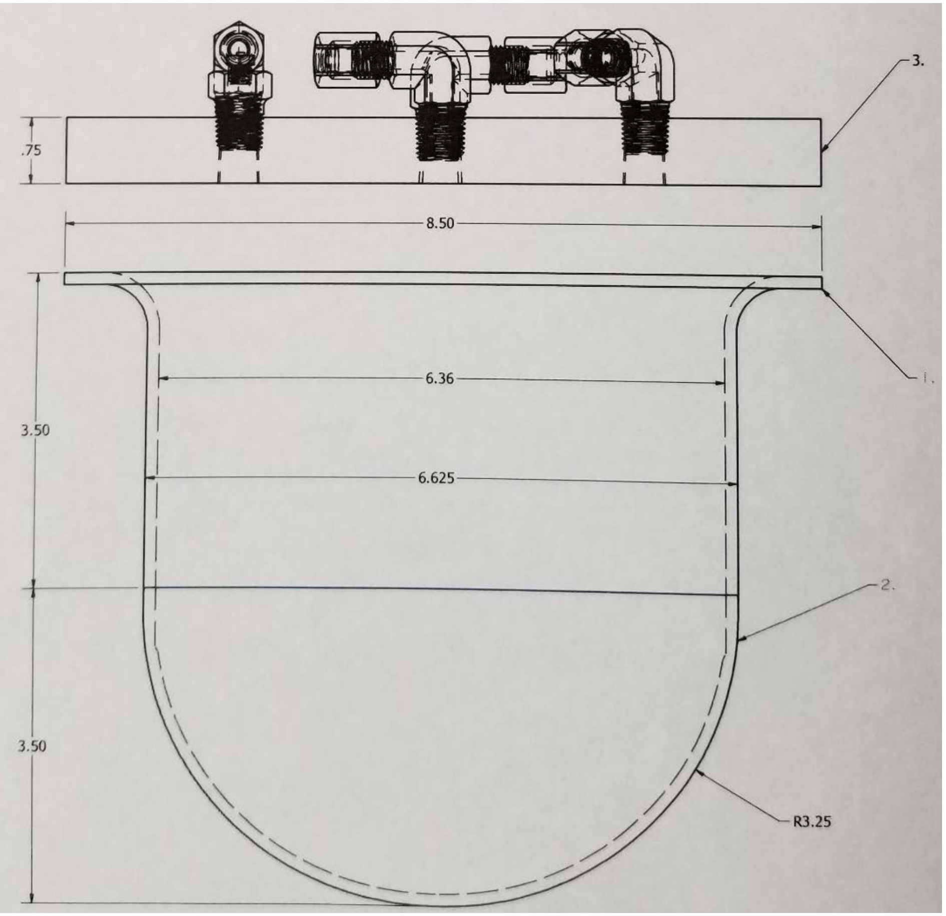


LTC 1871 DC voltage converter

Test volume fabrication



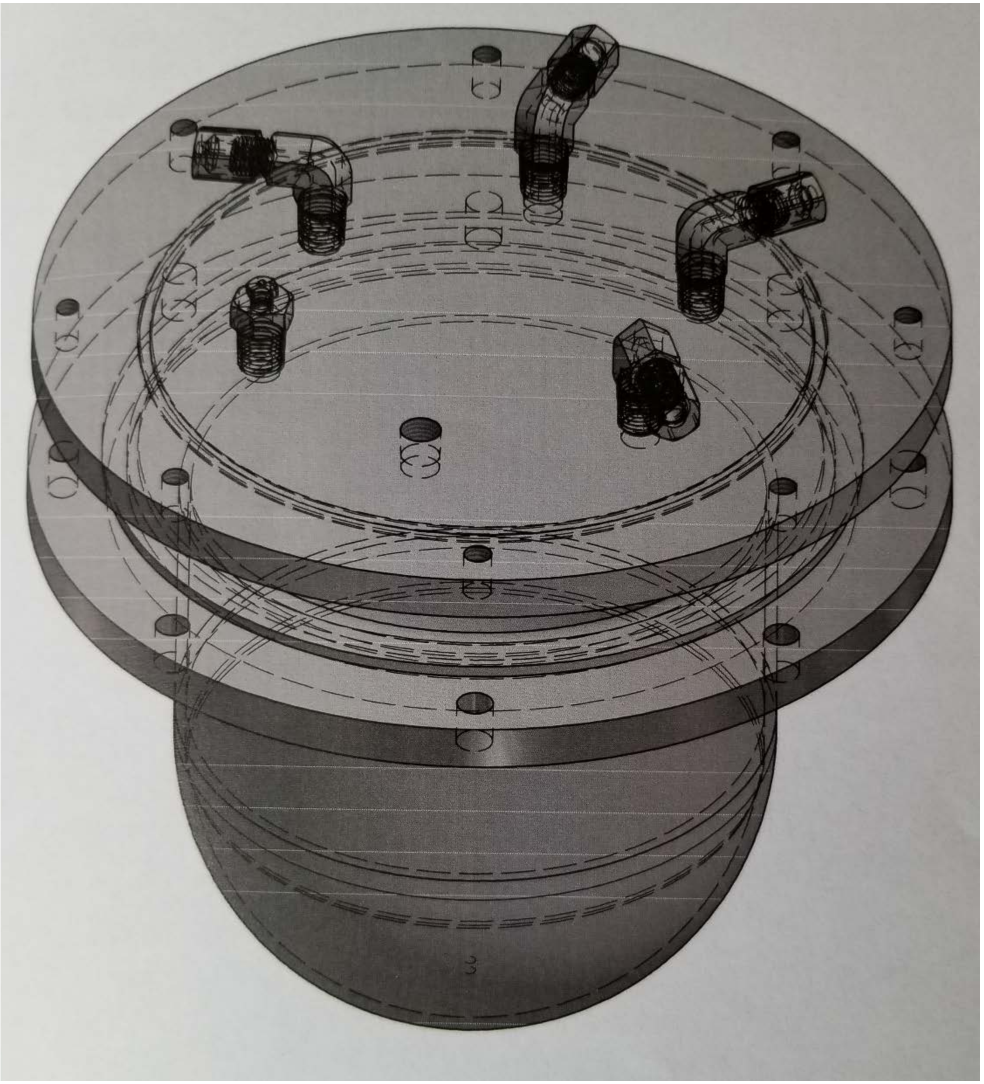
Schematic of test volume lid with penetrations



Schematic of test volume lid with dimensions

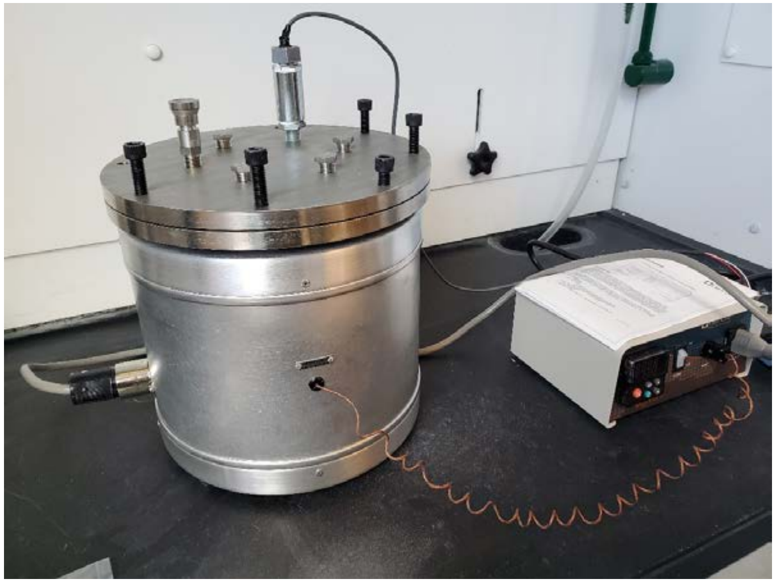
Test volume fabrication

3D schematic of
test volume



Status of collaboration with ISU

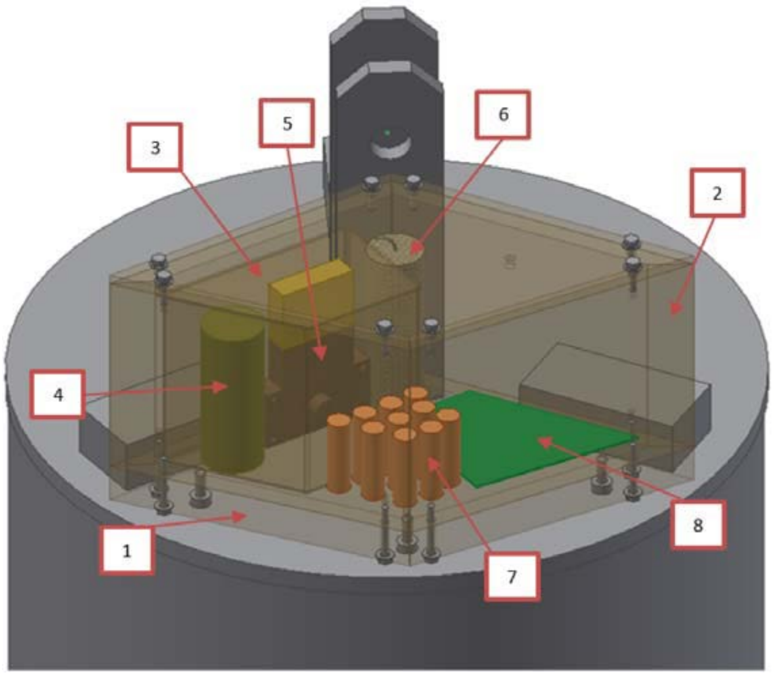
- Key components selected and purchased
- Test chamber fabricated and operating
- Individual parameter testing for
  - Temperature, hydrogen, and relative humidity
- Sensor module successfully programmed to collect and periodically transmit data (T, RH, H_2, t, V) wirelessly to a CSV file format

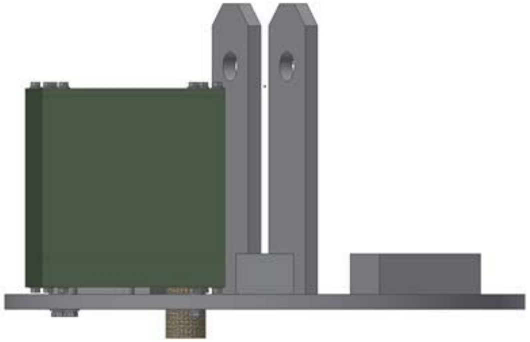


Westinghouse work scope

Westinghouse work scope

- Enclosure CAD model developed
    1. Tungsten shield/base
    2. Outer enclosure
    3. Inner enclosure
    4. Pressure sensor
    5. Hydrogen sensor
    6. Radiation sensor
    7. Battery bank
    8. Printed Circuit Board (PCB)

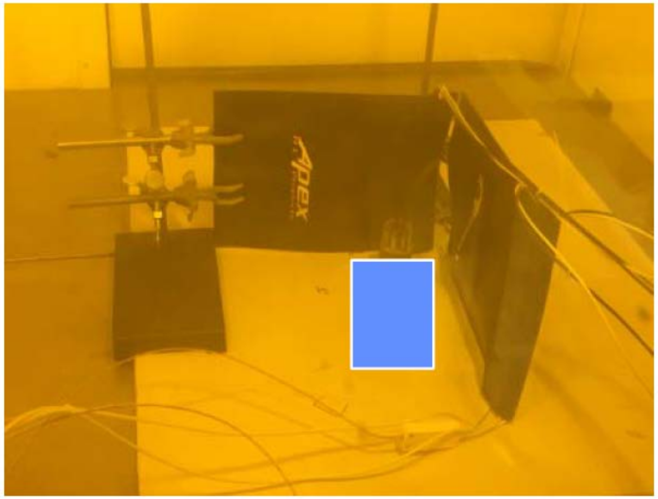




Courtesy of Westinghouse: Jorge Carvajal

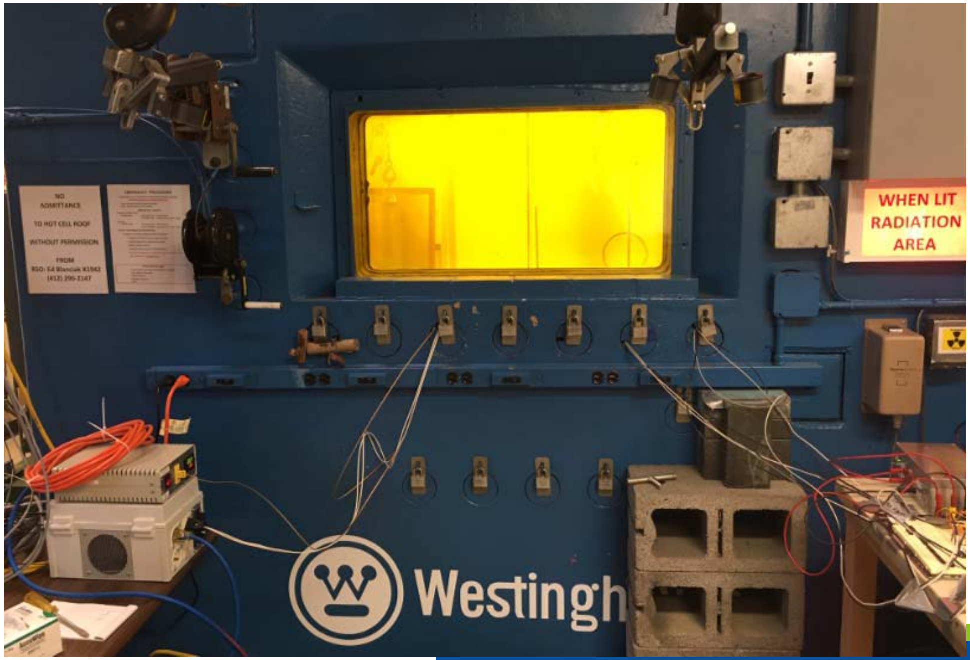
Battery irradiation and temperature testing

- Two lithium-based battery types tested
  - AA and ½ AA size
  - 1600 mAhr and 600 mAhr
  - Irradiations at room temperature and 100°C

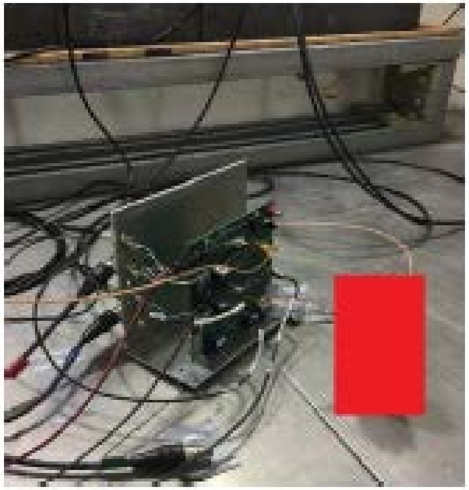


Co-60 source purposely occluded by blue rectangle

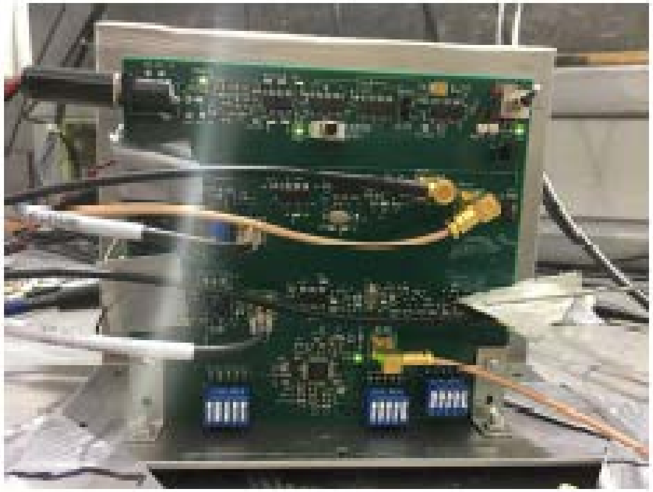
Courtesy of Westinghouse: Jorge Carvajal



In-canister hardware irradiation tests



Co-60 source purposely occluded by red rectangle



In-canister hardware PCB

Courtesy of Westinghouse: Jorge Carvajal

In-canister hardware irradiation data acquisition system

Wireless transmission tests

- Transmitter antennas and piezoelectric transducer placed inside bottom bucket
- Receiver antennas and microphone connected to spectrum analyzer and oscilloscope, respectively, on the lid
- Signal transmission path entirely inside canister through metal brackets and divider plates

Microphone on lid penetration

Antennas in interior of bottom bucket

2.4 GHz transmitter connected to bottom bucket antenna

Courtesy of Westinghouse: Jorge Carvajal

Status of Westinghouse collaboration

- Key components selected and purchased
- Fabricated mock-up for wireless testing
- Completed irradiation testing of in-canister components
- Completed temperature and humidity testing of components
- Verified wireless transmission using radio frequency and acoustic signals

Conclusion and path forward

- Successful RCMS will provide data to help better understand ASNF extended dry storage
- Feasibility studies for three developmental approaches
  - Completed feasibility study for point data and wired approach
  - Completed feasibility study for wireless approach
- Current activities
  - Engage Westinghouse on refining and developing wireless approach
  - Engage CPP-603 to identify operations requirements for prototype

Questions?