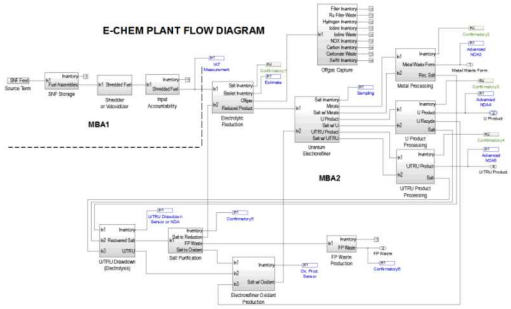
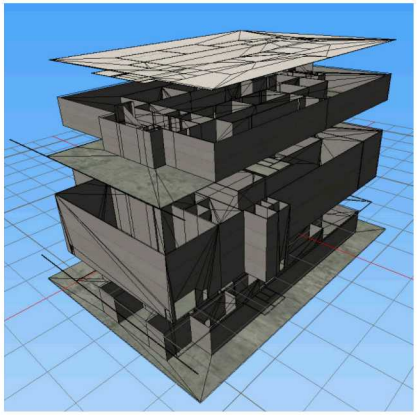
SAND2018-10206PE

Milestone 2020 (Echem) Modeling - Safeguards and Security





PRESENTED BY

Ben Cipiti

TEAM

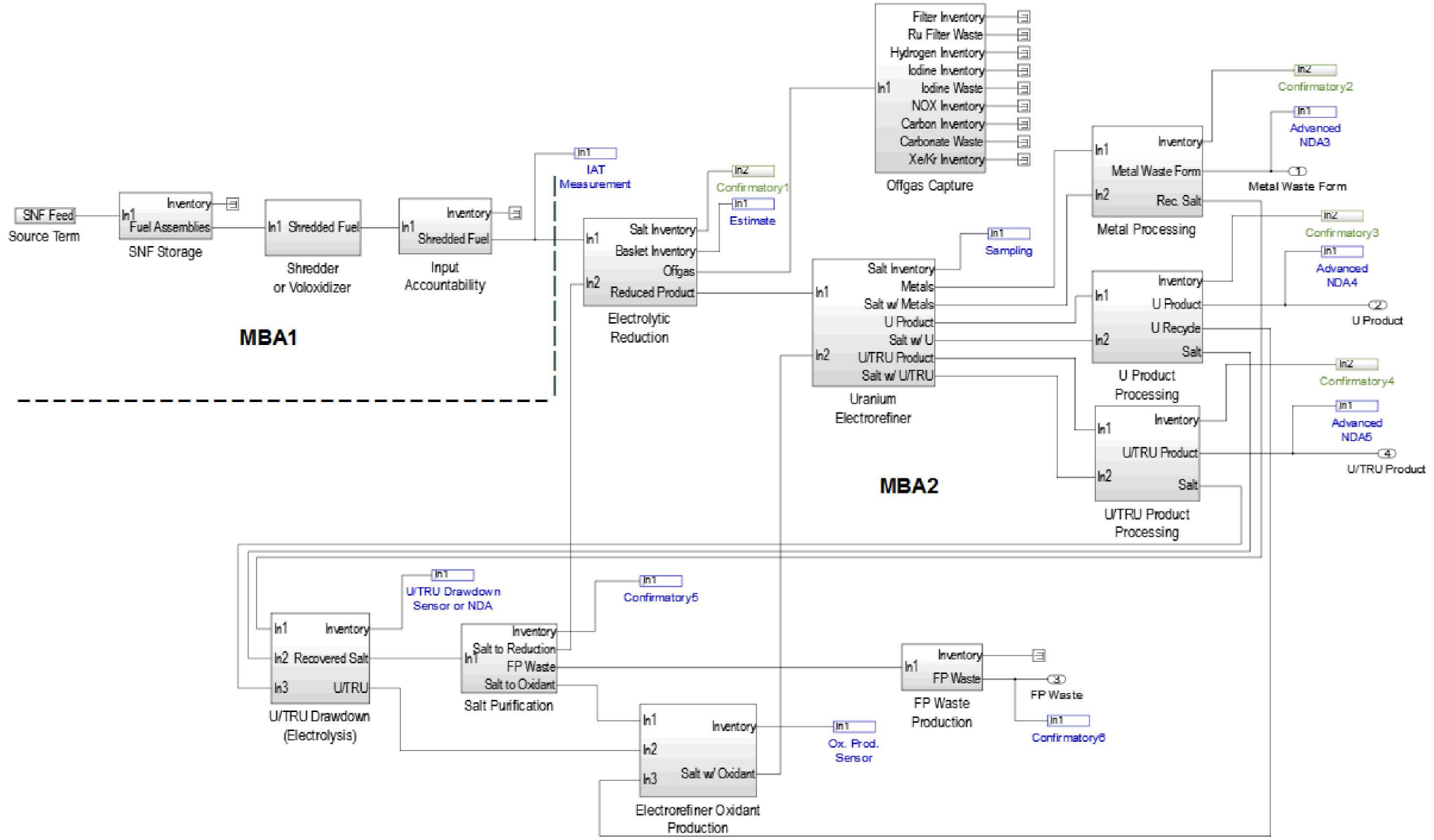
Nathan Shoman, Jordan Parks, Tam Le, Brian Jeantete, Todd Noel, Ryan Knudsen, Mario Morford-Oberst

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Safeguards Modeling for the 2020 Milestone

- **The safeguards model has two main tasks toward meeting the Echem 2020 milestone:**
  - Develop an overall safeguards approach for electrochemical facilities, including options.
  - Determine the safeguards performance metrics through diversion scenario analysis.
- **The SSPM was updated for better integration with the rest of the campaign:**
  - Improvement to the GUI, standardization of output data, addition of full isotopic tracking, integration with GADRAS, expansion of statistical tests, evaluation of machine learning algorithms.
- **Using our baseline design, the diversion scenario analysis was updated.**
- **These results were included in the June deliverable.**

Echem Flowsheet

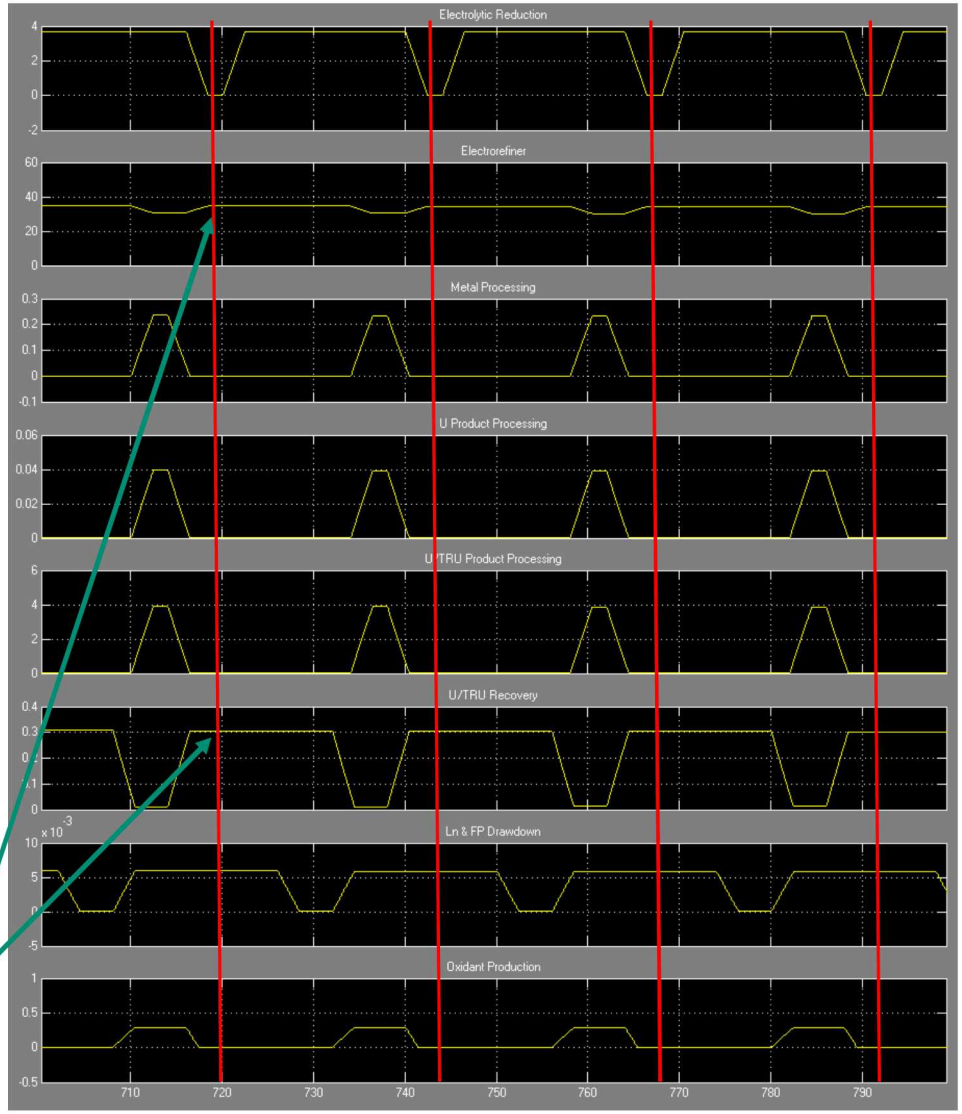


Safeguards Challenges/Opportunities

- **Plant Flushouts** – Some plant designs are not suited to a yearly plant flushout, so will require reliance on inventory measurements.
- **Input Accountability** – Key challenge since fuel is not dissolved before processing.
- **Obtaining Representative Salt Samples** – Salts can have inhomogeneities.
- **Accountability of U and U/TRU products** – Metallic products present different measurement forms.
- **Confirmatory Measurements in the Hot Cell** – Challenges with the high dose environment.
- **Process Monitoring Information** – Echem has unique additional information that can be part of the safeguards approach.

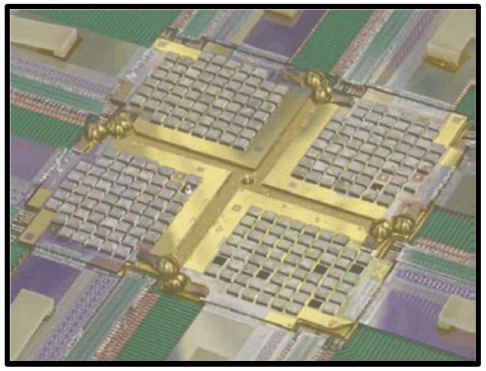
Baseline Safeguards Approach

- **The baseline approach assumes a periodic material balance period with no yearly plant flushout.**
  - Period is likely to be every 1-3 months.
  - The reduced number of processing units makes this more feasible for echem (as compared to aqueous).
- **Inputs and Outputs are always measured.**
- **Plant inventory is measured every 1-3 months.**
  - We have spent time evaluating the timing sequence in order to minimize the number of vessels that need to be measured with precision.
  - At the time of the material balance, actinides are present in only the electrorefiner and drawdown vessels



Input Accountability

- **The baseline approach is some type of homogenization or representative sampling of the shredded fuel, followed by DA.**
  - How well this will perform is still unknown (perhaps 2-3%)?
- **NDA approaches are also being considered, including microcalorimetry.**

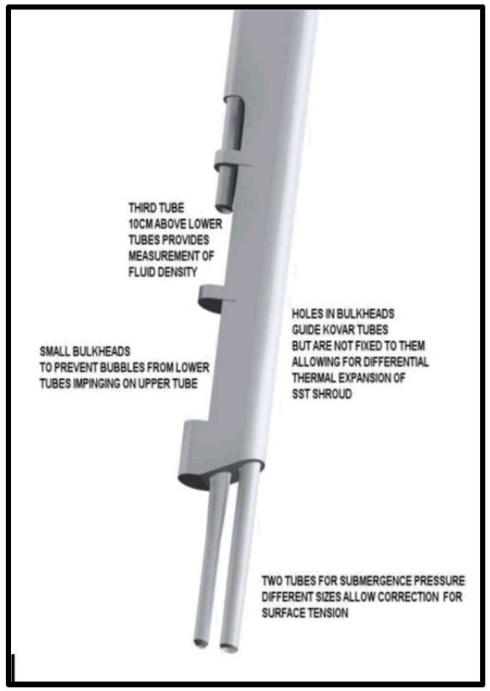


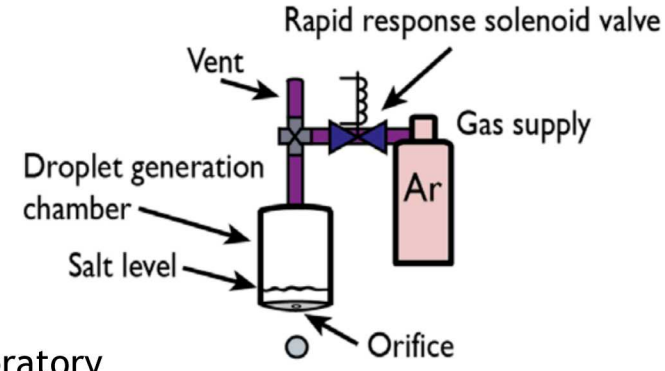
- **An alternative approach can use the ER vessel to establish input accountability, but requires a particular plant design. If U extraction only occurs while spent fuel is in the basket, a measure of the increase of Pu in the salt can be used to establish the input. Then if the U/TRU extraction occurs with only DU in the basket, the Pu in the U/TRU product should balance with the change in the salt.**

Microcal: Croce et al., Los Alamos National Laboratory

Salt Sampling

- **Since the ER salt contains high quantities of actinides, precision measurements are required.**
- **The triple bubbler and micro-droplet generator are two technologies that are being developed.**
- **The ER vessel can have debris on the bottom, fines in the salt (likely U), and dross on the top.**
  - These are likely engineering issues that can be resolved through operations.

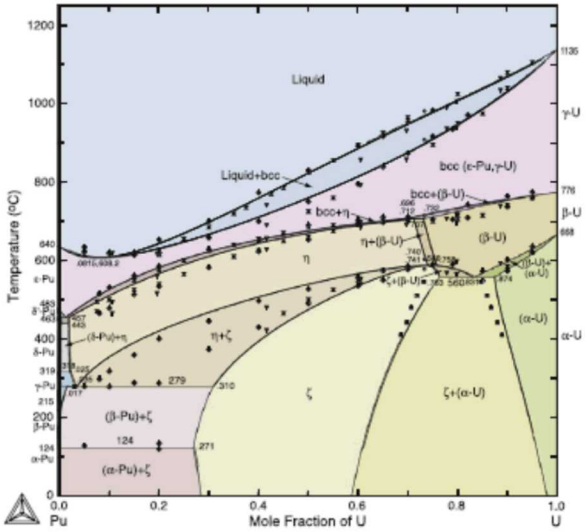




Bubbler: Williams et al., Idaho National Laboratory
Micro-Analytical Sampling: Launiere et al., Argonne National Laboratory

Measurements of U and U/TRU Products

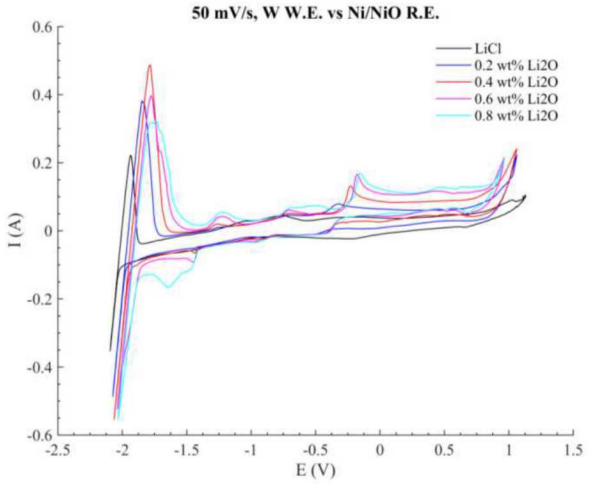
- **The baseline approach is to sample the products during melting followed by DA, but this may be burdensome for routine measurements.**
- **NDA measurements would be preferable, and the High Dose Neutron Detector and In Situ Actinide Monitor are two technologies which may be applicable.**
- **Waste forms also could be measured with neutron or gamma measurements.**



HDND: Henzlova et al., Los Alamos National Laboratory
In Site Actinide Monitor: Westphal et al., Idaho National Laboratory

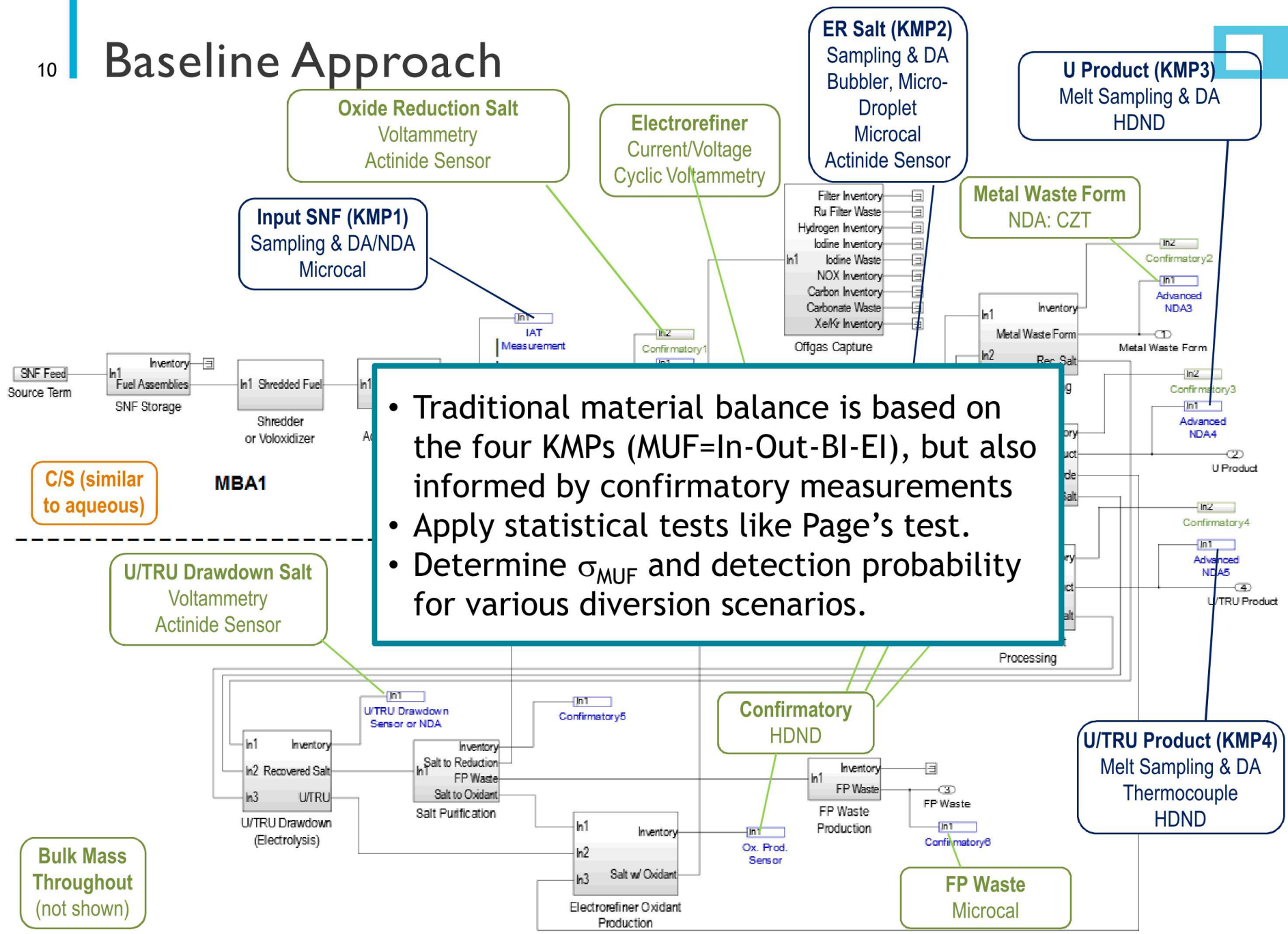
Confirmatory Measurements in the Hot Cell

- **A number of unit operations will contain no or only trace actinides during the inventory balance, but confirmatory measurements are required.**
- **The High Dose Neutron Detector is also being examined for this role, as well as voltammetry for salts that should have no or low quantities of actinides.**



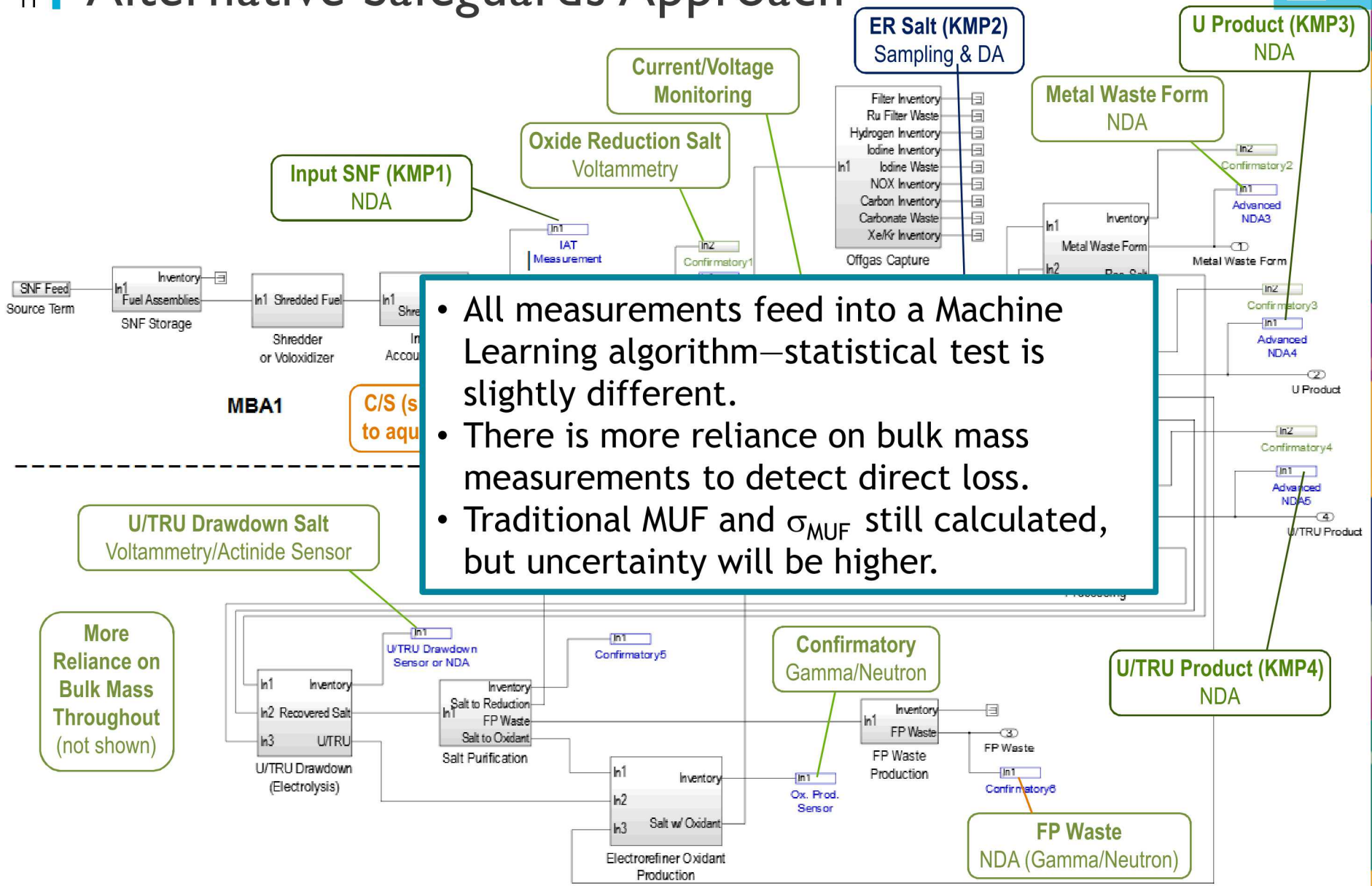
HDND: Henzlova et al., Los Alamos National Laboratory
Voltammetry: Williams et al., Idaho National Laboratory
Williamson & Willit, Argonne National Laboratory

Baseline Approach



- Traditional material balance is based on the four KMPs (MUF=In-Out-BI-EI), but also informed by confirmatory measurements
- Apply statistical tests like Page's test.
- Determine σ_{MUF} and detection probability for various diversion scenarios.

Alternative Safeguards Approach



- All measurements feed into a Machine Learning algorithm—statistical test is slightly different.
- There is more reliance on bulk mass measurements to detect direct loss.
- Traditional MUF and σ_{MUF} still calculated, but uncertainty will be higher.

Diversion Scenario Analysis Results

- **The overall materials accountancy approach was robust to detecting diversions from different locations.**
- **Key take-away is that for a 100 MT/yr facility, in order to meet IAEA regulations (95% probability of detection of 8 kg of Pu within one month) the measurement uncertainties needed to be:**
  - 3% for input and output measurements
  - 1% for the ER salt measurement
- **Addition Points:**
  - One month balance period was assumed.
  - Only abrupt loss (diversion within one month) could meet the requirement.
  - Smaller facility sizes will relax the uncertainty requirement.

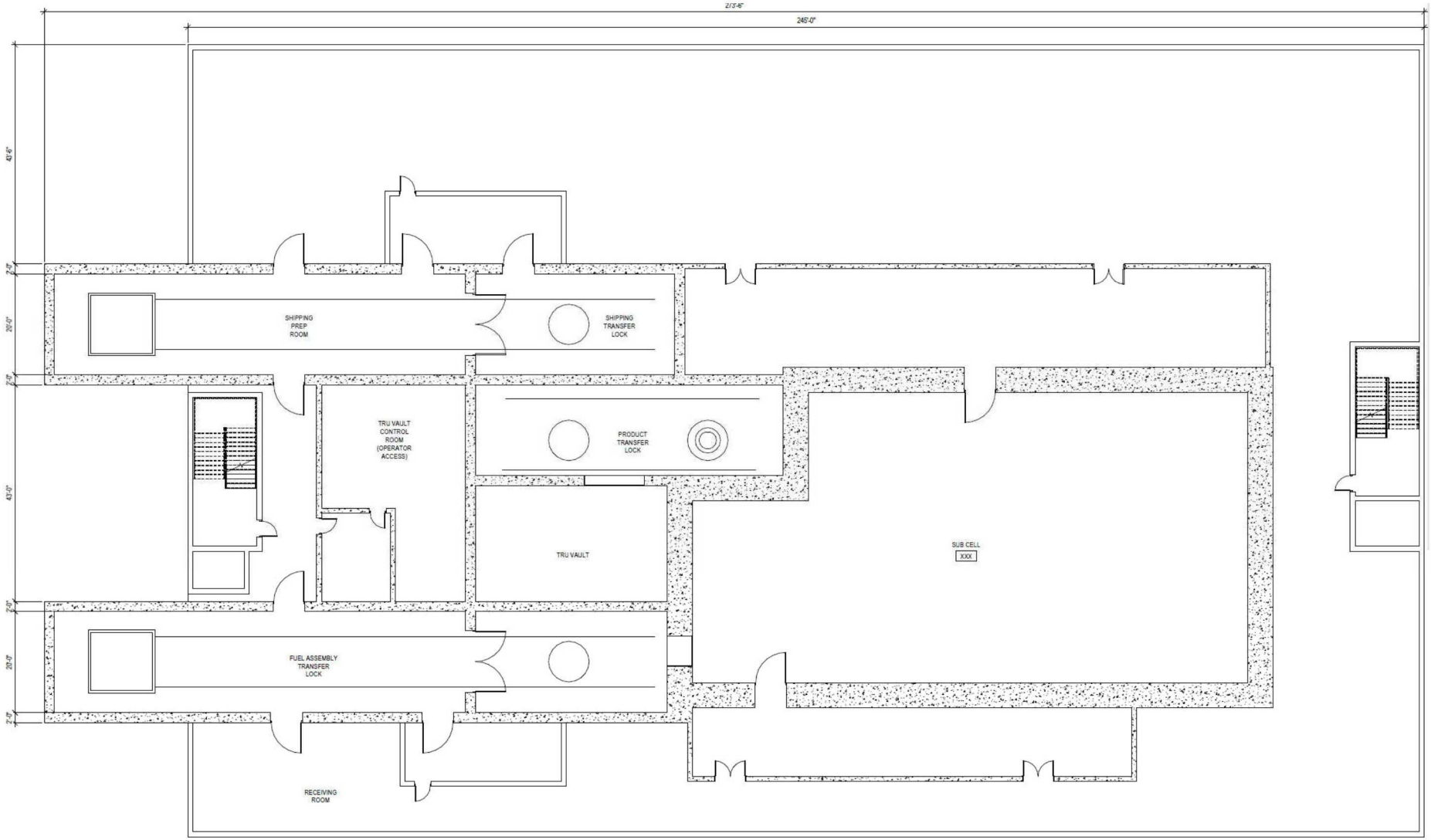
Echem Safeguards Modeling Next Steps

- **Receive an updated baseline flowsheet from ANL.**
- **Make minor modifications to the SSPM to be consistent with the baseline flowsheet.**
- **Provide updated data to others in the campaign as needed.**
- **Update the safeguards results:**
  - Continue to perform a parametric analysis.
  - Expand the scenarios (direct versus substitution).
  - Take into account plant scaling.
  - Incorporate data fusion (NEUP) and machine learning options.

Security Modeling for the 2020 Milestone

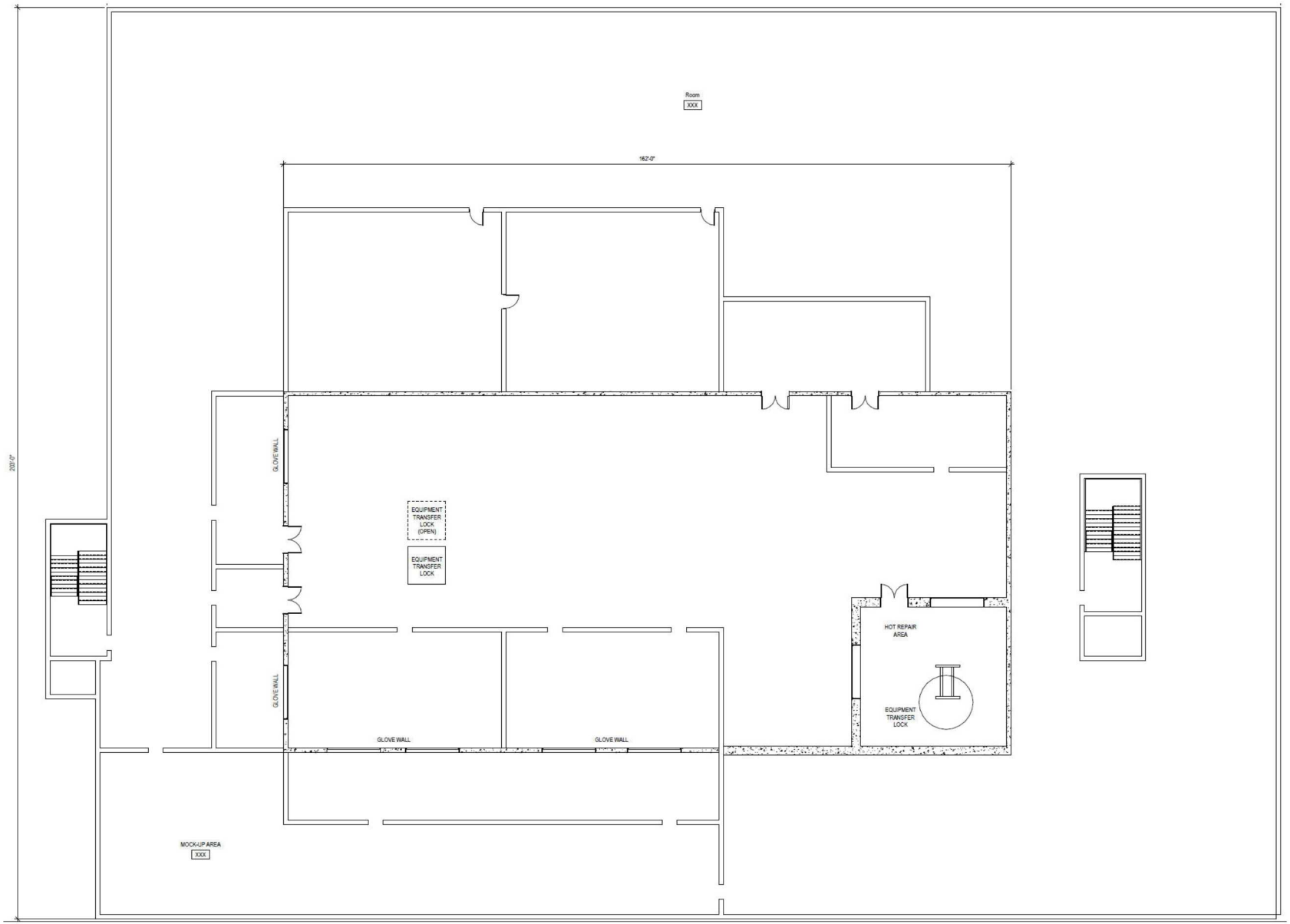
- **The security modeling work for Echem was re-initiated in early Summer.**
- **A high fidelity model of an electrochemical reprocessing plant is being created for development and testing of a security approach:**
  - A generic facility design has been developed.
    - Design based on a combination of the Frigo (2003) and Burns and Roe (1995) reports along with previous SNL studies. Also incorporating security-by-design findings from previous work.
  - The facility is modeled in STAGE for high fidelity visualization and security analysis.
  - Example scenarios will be generated using the Scribe3D scenario analysis and visualization toolkit.
  - A December 2018 report will summarize the model development and demonstration of two scenarios.

Basement Level



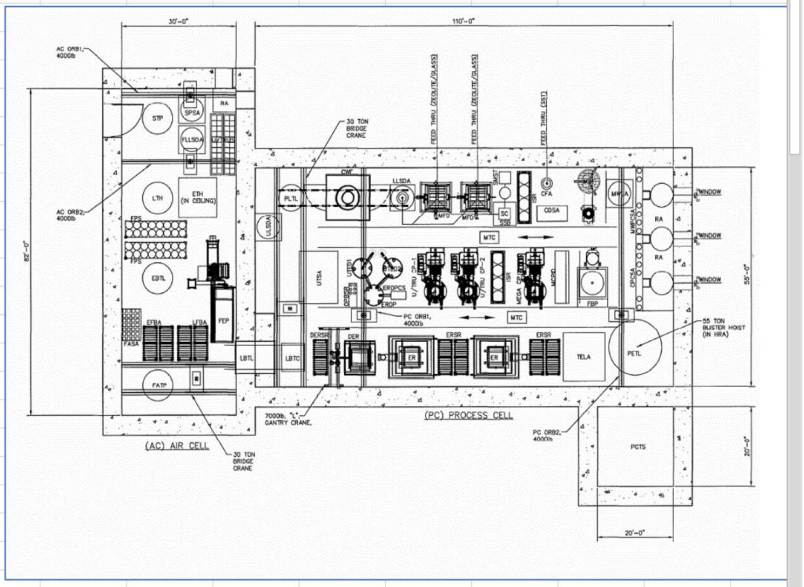
Operating Level

Second Floor



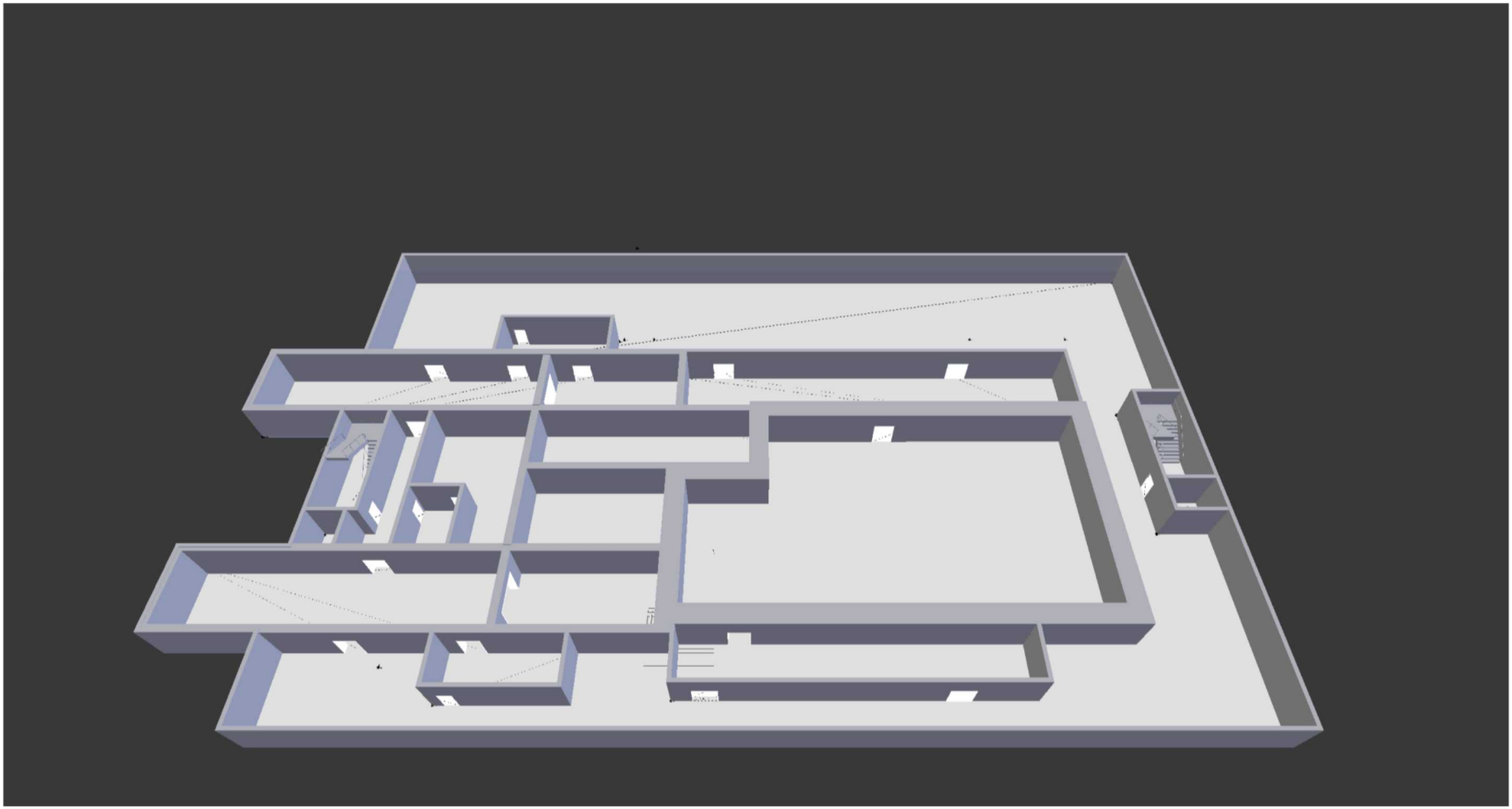
Equipment List

Equipment Name	Process Step	Location	Number of U	Footprint	Photo
Chopper Shredder Devic	1	Air Cell		306 in. long 72 in. wide (	sq ft)
Fuel Processing Baskets	1	Air Cell and Argon Cell		N/A	
Direct Electrolytic Reduc	4,5	Argon Cell		98 in. by 94 in. (64 sq ft)	
Electrorefiner	6	Argon Cell		138 in. wide 122 in. tall (	sq. ft.)
Cathode Processor Crucil	6	Argon Cell			
ER Oxidant Production	7	Argon Cell			
EROP Casting Station	7	Argon Cell			
Cathode Processor	8	Argon Cell		15 ft. by 15 ft.	
CP Crucible	8	Argon Cell			
Inverter	9	Argon Cell			
Mega Cathode Processor	9	Argon Cell			
Electrorefiner Storage Ra	10	Argon Cell			
Fuel Assembly Ends Cont	10	Argon Cell			
Metal Waste Furnace	10	Argon Cell			
Metal Waste Process Cru	10	Argon Cell			
Metal Waste Receiver Cr	10	Argon Cell			
U/TRU Storage Area	10	Argon Cell			
U/TRU Crucible Salt Stora	10	Argon Cell			
Crucible Preparation Mat	11	Argon Cell			
Fuel Basket Process	11	Argon Cell			
Ingot Dumper	11	Argon Cell			
Ingot Storage Rack	11	Argon Cell			
Master Slave Manipulato	11	Argon Cell			
Metal Waste Upper Asse	11	Argon Cell			
Electrolysis Hardware	12	Argon Cell			
Salt Transfer Line 1A/2A	12	Argon Cell			
U/TRU Electrolysis and TI	12	Argon Cell			
U/TRU Crucible	12	Argon Cell			
U/TRU Product Processin	12	Argon Cell			
Ceramic Waste Process C	13	Argon Cell			
Oxidant Product Basket	13	Argon Cell			
Salt Transfer Line 1B/2B	13	Argon Cell			
TRU Drawdown Crucible	13	Argon Cell			

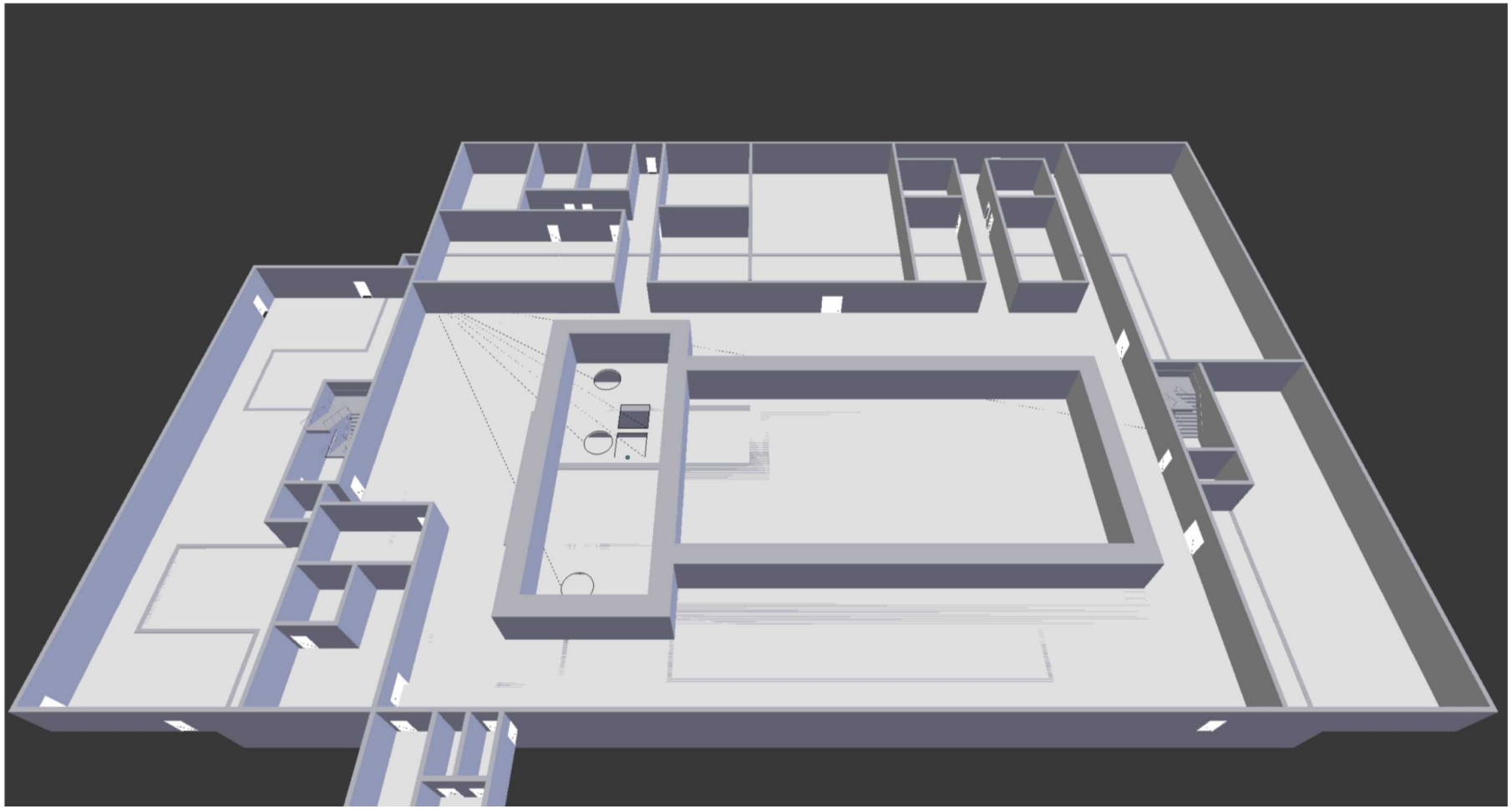


A.A. Frigo, D.R. Wahlquist, J.L. Willit, "A Conceptual Advanced Pyroprocessing Recycle Facility," Global 2003, New Orleans, LA (November 16-20, 2003).

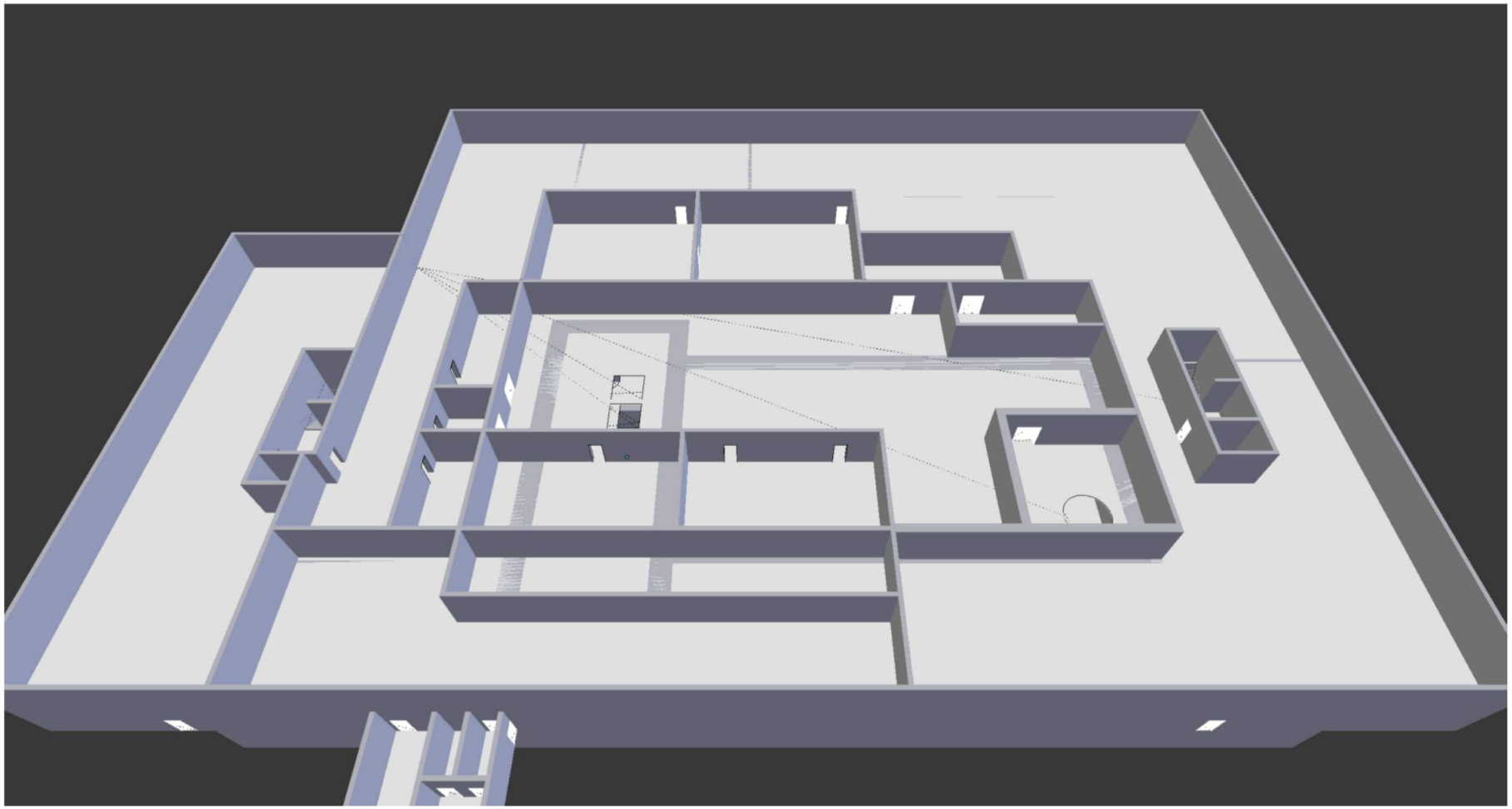
Basement Level (3D Model)



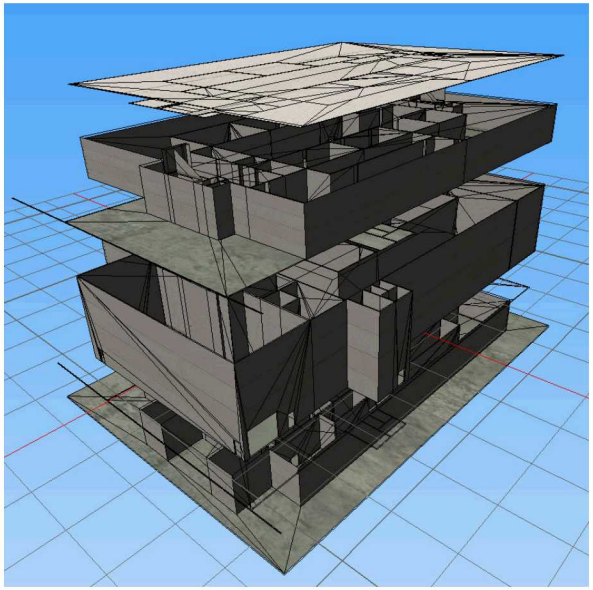
Operating Floor (3D Model)

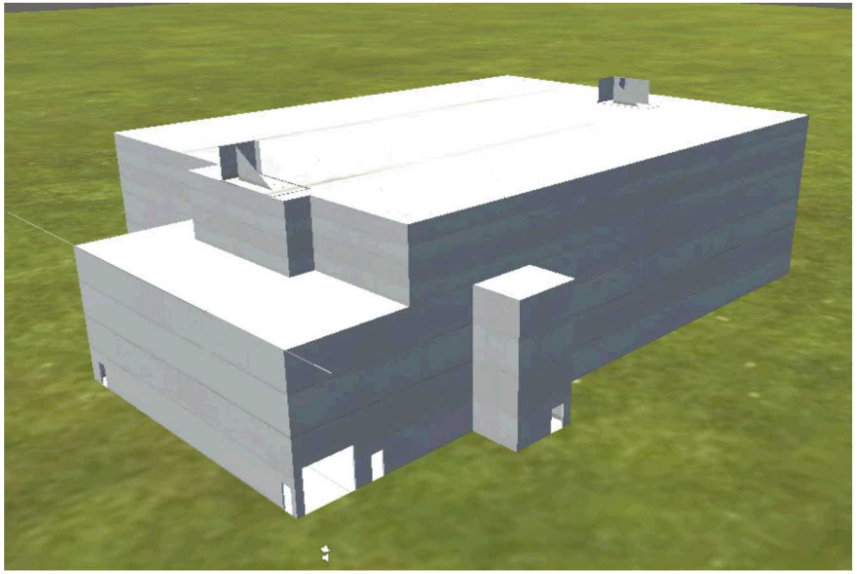


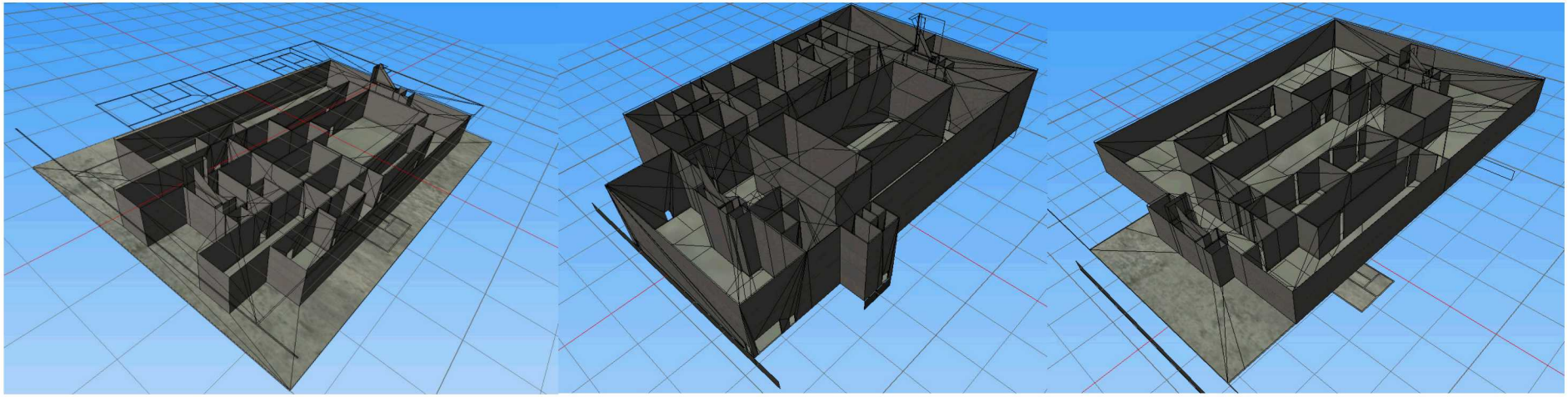
Second Floor (3D Model)



Complete STAGE Model







Security Modeling Next Steps

- **Physical protection elements (portal monitors, cameras, guards, etc.) need to be added.**
- **The model will be developed for two example scenarios:**
  - Notional outsider attack (possibly sabotage).
  - Notional insider attack (theft).
- **The goal for the December milestone is to get the STAGE model developed and working through demonstration of the two scenarios.**
- **The rest of FY19 and into FY20 will focus on the analysis.**
  - Multiple scenarios will be evaluated to generate security metrics (probability of adversary success, etc.).
  - A key goal is to demonstrate an optimized security design to minimize cost.