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Insights from a Joint US/India Workshop on Modeling and Simulation for Improved Nuclear Material Accountancy

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July 27, 2022

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Introduction

- Achieving material control and accountancy (MC&A) goals for large throughput bulk handling facilities is challenging
  - Driven by measurement uncertainties and process complexity
- Ongoing joint effort between U.S. National Nuclear Security Administration (NNSA) and Bahabha Atomic Research Center (BARC) is exploring modeling and simulation (M&S) to improve MC&A for bulk facilities
- Workshop was conducted in early 2022 to facilitate dialog between research staff, facility operators, and safeguards practitioners on M&S for improved facility safeguards

Workshop overview

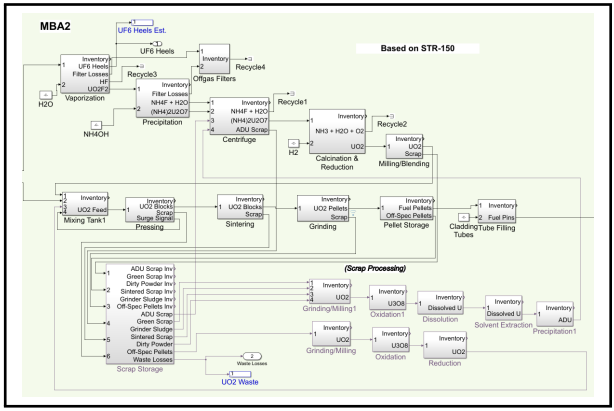
- **Title**: Fundamentals of Modeling and Simulation for Improved Nuclear Material Accountancy
- **When**: January 17-20, 2022
  - Four hour sessions (early morning EST, late evening IST)
- **Who**: Sandia National Laboratories (SNL) and Bhabha Atomic Research Centre (BARC)
  - SNL Organizers: Nathan Shoman, Dr. Benjamin Cipiti, Philip Honnold, and Dr. Michael Higgins
  - BARC Organizers: Dr. Neetika Rawat and Dr. Ankita Rao
  - Approx 15 Indian attendees and 10 U.S. attendees
- **What**: The use of modeling and simulation to improve Nuclear Material Accountancy (NMA) at real-world facilities

Motivation: M&S can be a quick, cost-effective way to test different MC&A strategies

- Retrofits of existing facilities to improve safeguards can be expensive
  - Equipment costs
  - Performance evaluations
  - Training costs
- M&S can be used to consider “what-if” scenarios
- Dialog with facility staff and safeguards practitioners are key

Separation and Safeguards Performance Model (SSPM) supports a wide range of safeguards analyses

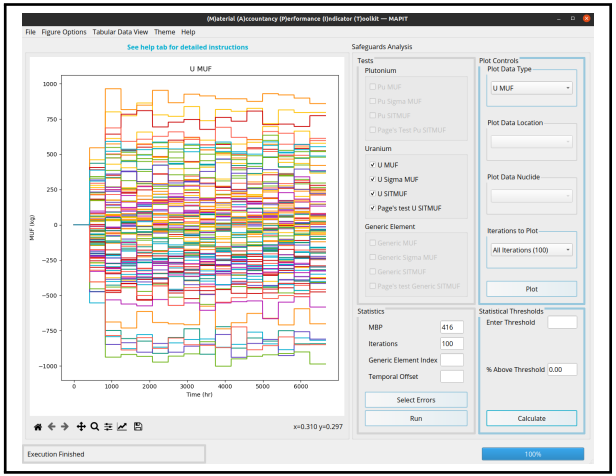
- SSPM flowsheets exist for several different facilities
- Standardized feature set regardless of flowsheet
  - Reactor physics based source terms
  - Elemental and isotopic tracking
  - Customizable measurement points
  - Diversion scenario analysis
  - Integration with external codes
  - Automated calculation of safeguards statistics



Visual diagram for MBA2 of the SSPM fuel fabrication model

Material Accountancy Performance Indicator Toolkit (MAPIT) is a open-source standalone safeguards tool

- MAPIT analyses previously generated datasets to calculate safeguards statistics
  - Automated error propagation
  - Automated calculation of statistical tests (MUF, σ_{MUF}, SITMUF, Page's trend test)
  - Threshold optimization
  - Visualization tools
  - Flexibile I/O tools



Overview of MAPIT analysis area

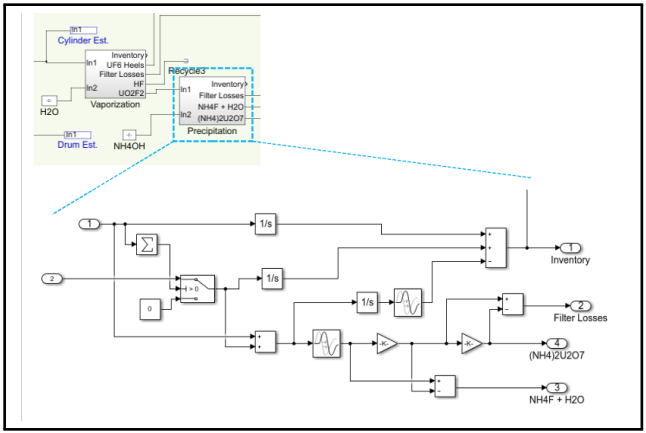
Workshop overview

- Foundations
  - Nuclear Material Accountancy (NMA), Statistics, Propogation of Variance (POV), Control Charts
  - MUF, SITMUF, Page's trend test
- Non-destructive Assay (NDA) and Destructive Assay (DA) Foundations
- Facility Applications
  - Fuel fabrication case studies
- Modeling and Simulation
  - Simulink introduction
  - Examples of operations modeling
- Interactive MAPIT exercises

Lecture highlights

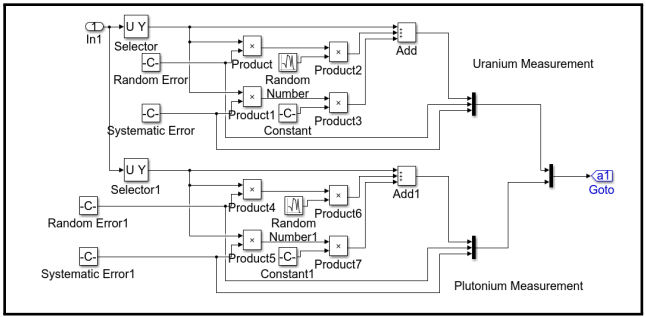
Modeling and simulations foundations: process models

- Signals (i.e., material flows) connect multiple blocks (i.e., subprocess models) in Simulink models
  - Tracking on a per isotope basis
- Process operations are modeled by manipulating signals
  - Precise timing modeling required
- Use of Scopes can provide an intuition for facility operation



Modeling and simulations foundations: measurement errors

- Realistic measurement error is an important component to evaluate safeguards performance
- SSPM measurement error can show “real-time” behavior
- Can be slow if large aggregate statistics are needed
  - MAPIT can utilize data from SSPM for robust, light-weight statistical calculations



Case studies

- Hand calculations demonstration application of techniques discussed in class

U Data (kg)			
Time (h)	**UF_6 Cylinders**	**UO_2 Drums**	**UF_6 Precipitation Inventory**
224	2001.8	289.9	3.9
448	4666.2	679.1	13.5
672	4658.9	676.5	23
...	...	...	...

Example MB calculation

$$\text{MUF}_{t=448} = \underbrace{679.1}_{UO_2\ \text{Drums}} + \overbrace{4666.2}^{UF_6\ \text{Cylinders}} + \underbrace{(13.5 - 3.9)}_{UF_6\ \text{Precipitation Inventory}} - \overbrace{\ldots}^{\text{Other inv.}} - \underbrace{\ldots}_{\text{U outputs}}$$

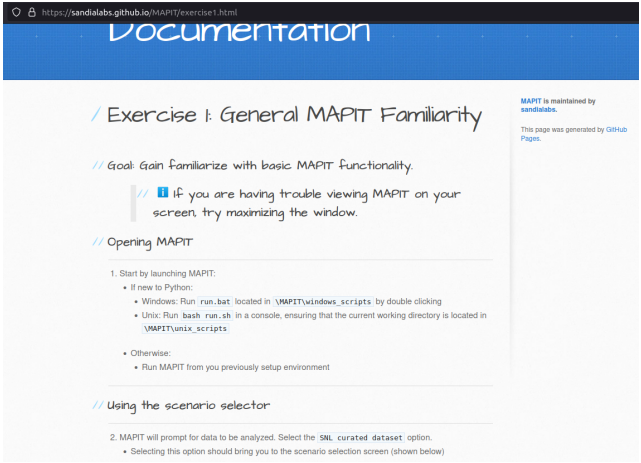
Interactive exercises

Motivation: Engage participants while delivering meaningful content

- Virtual setting can be a challenge to achieve high engagement
- Risk of “death by powerpoint”
- Diverse background of participants could make retaining high levels of participation challenging
- Counter by developing interactive exercises
  - Avoid needing specific hardware

MAPIT Workshop Exercises

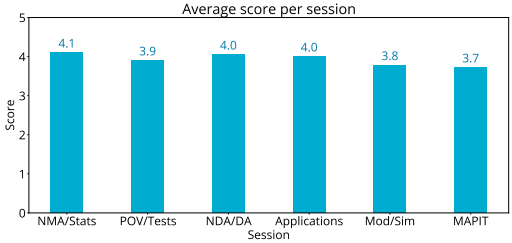
- Conducted a total of four exercises with participants:
  - MAPIT Basics
  - Measurement Error
  - Material Loss
  - Probability of Detection
- Insufficient time for bonus exercise five
  - System optimization
  - Specified false alarm and detection probability, determine cheapest system setup



Exercises available at `https://sandialabs.github.io/MAPIT/`

Workshop Feedback

- Feedback collected directly from participants (10) based on a set of questions agreed upon by US and BARC organizers
  - Interest in offline module offerings
  - Class too compressed
  - Desire for supplementary reading material beyond class materials
  - Desire for in-person learning
  - Facility operator perspectives desired
  - More concrete examples
  - Streamlined MAPIT install
- Metrics (1-5)
  - Average overall: 4
  - Average knowledge change: 1.45



Conclusions

- Conducted a joint workshop on modeling and simulation for improved MC&A using modeling and simulation
- Implemented and lead interactive exercises using open-source software
  - Could prove to be verstaile for multiple learning formats
- Good feedback from participants on post workshop survey
- Discussing next steps for follow-on trainings

Acknowledgements

This paper summarizes recent work funded through the U.S. Department of Energy's National Nuclear Security Administration. The authors would like to acknowledge the persistent support from Dr. P. K. Pujari, ex-Director, RC&IG, Mr. V.K. Sinha, GCNEP, Mr. Ranajit Kumar, DAE and Mr. Padmakumar, DAE.