Quantifying the Impact of Antineutrino Detection on IAEA Safeguards Using the LISSAT Approach

This project is a joint collaboration between
Lawrence Livermore and Sandia National Laboratories

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Talk Overview

- We are working to quantify and compare the effectiveness of different safeguards approaches
- Quantitative analysis of diversion scenarios is a key part of this effort –
  - we use LISSAT for systems analysis - Lawrence Livermore National Laboratory Integrated Safeguards System analysis tool
- We have analyzed one simple scenario with a PWR to illustrate the LISSAT Method
- Our ultimate goal is to directly compare antineutrino detection with other methods and identify the most suitable deployment strategy

LISSAT Analysis Outline

- Chose one diversion scenario to illustrate the LISSAT method
- Run reactor at 5% higher power than declared –for the following two cases
  - With current IAEA safeguards
  - With current IAEA safeguards and antineutrino detectors
- Calculate the reduction of the diversion path non detection probability with an antineutrino detector in pace

Current IAEA Safeguards Methods for Reactors

- Coded tags and seals placed on fuel assemblies, and measures such as video surveillance of spent fuel ponds and non-destructive assay.
- Methods do not provide real-time quantitative information about the reactor core power level and isotopic composition

Example Scenario – Timeline for Running Reactor at Higher than Declared Power

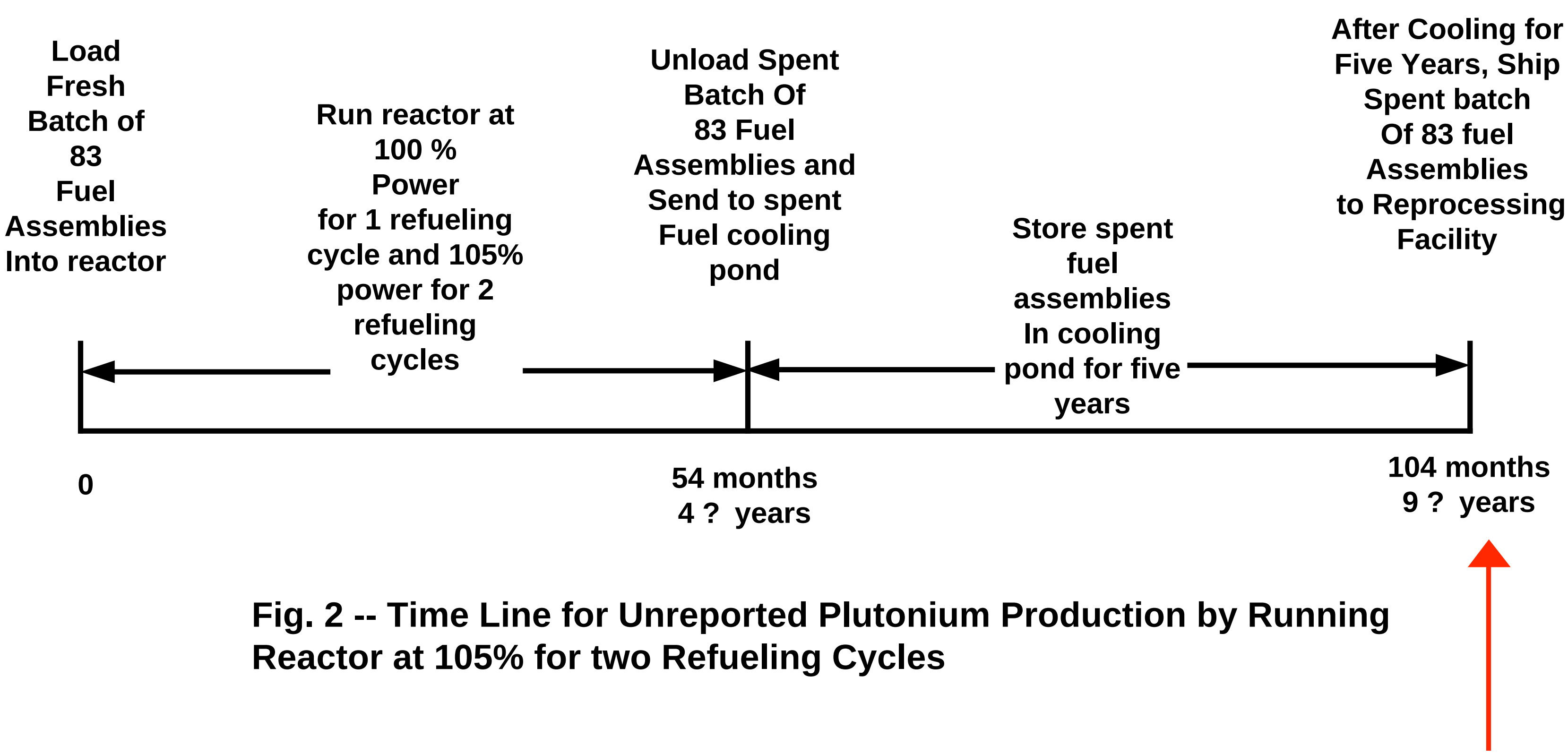
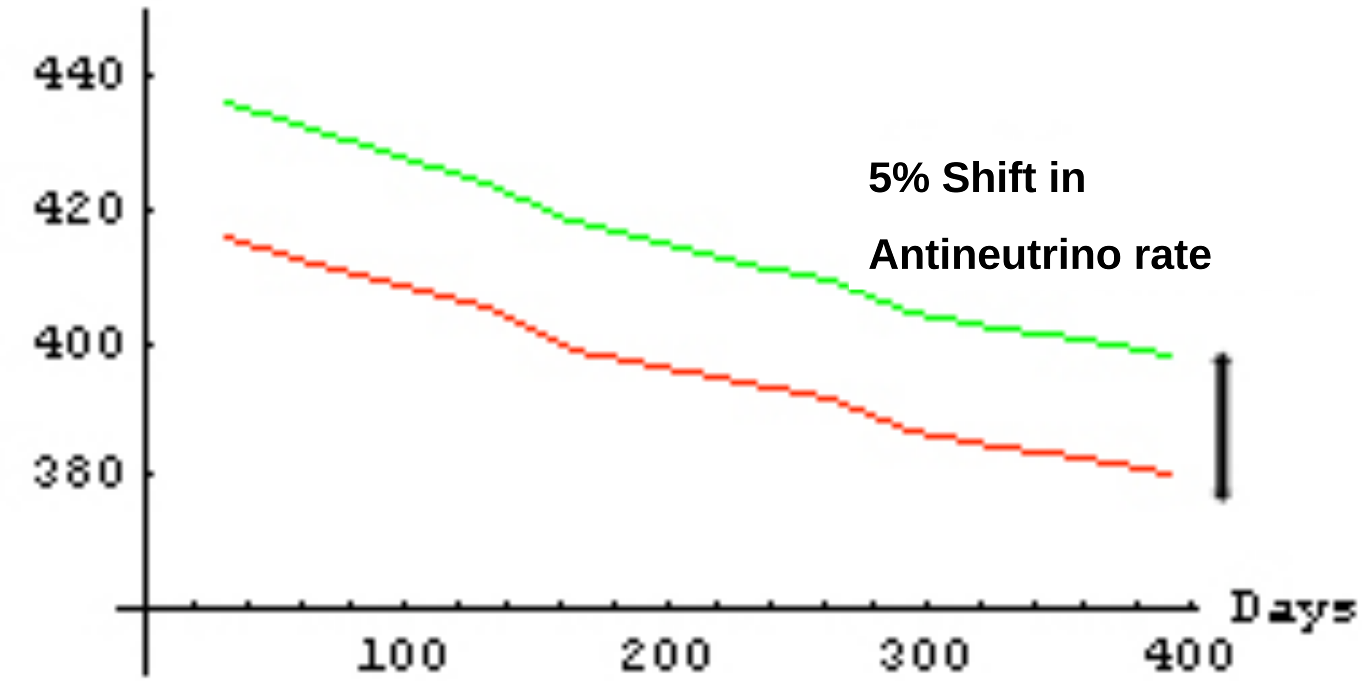


Fig. 2 -- Time Line for Unreported Plutonium Production by Running Reactor at 105% for two Refueling Cycles

Diversion of Additional 8 kg of Pu generated at higher power occurs at the reprocessing plant

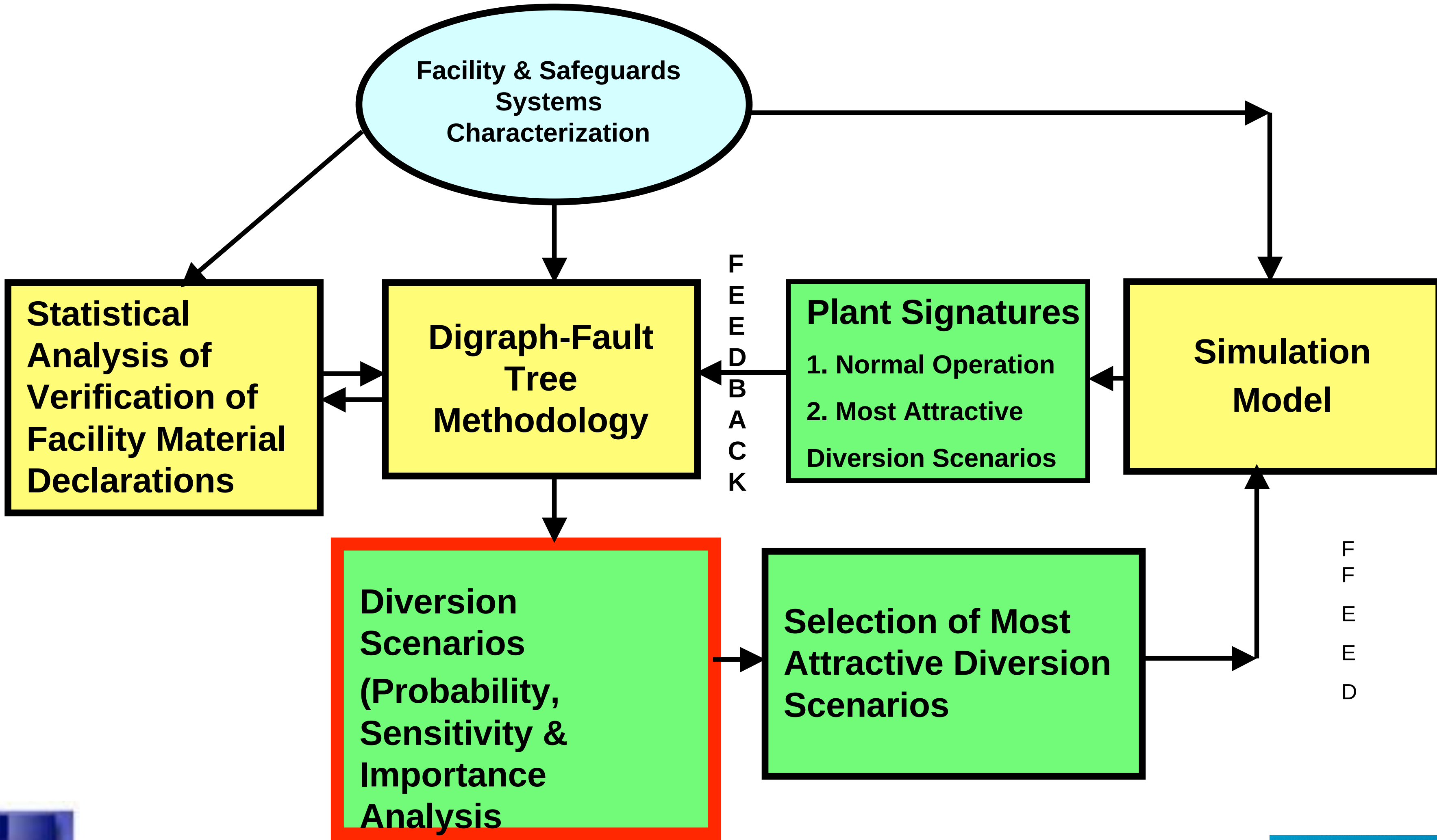
Antineutrino Count Rate – with and without 5% shift in power (Reactor Simulation)

Anti neutrino events

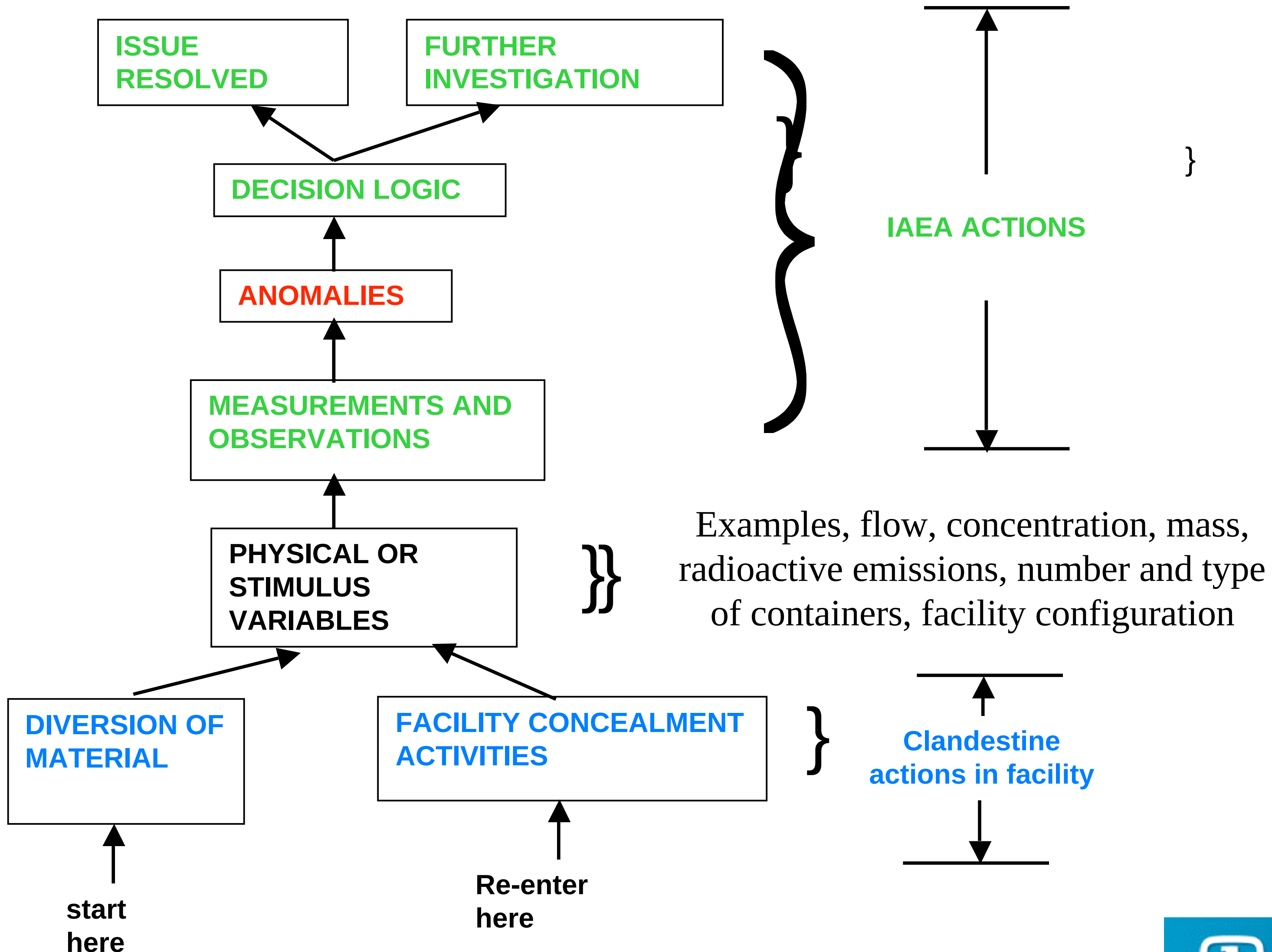


Antineutrino rates arising from a standard PWR core in an "equilibrium" cycle
(ORIGEN simulation using the NRC San Onofre Final Safety Analysis Report for input isotopics)

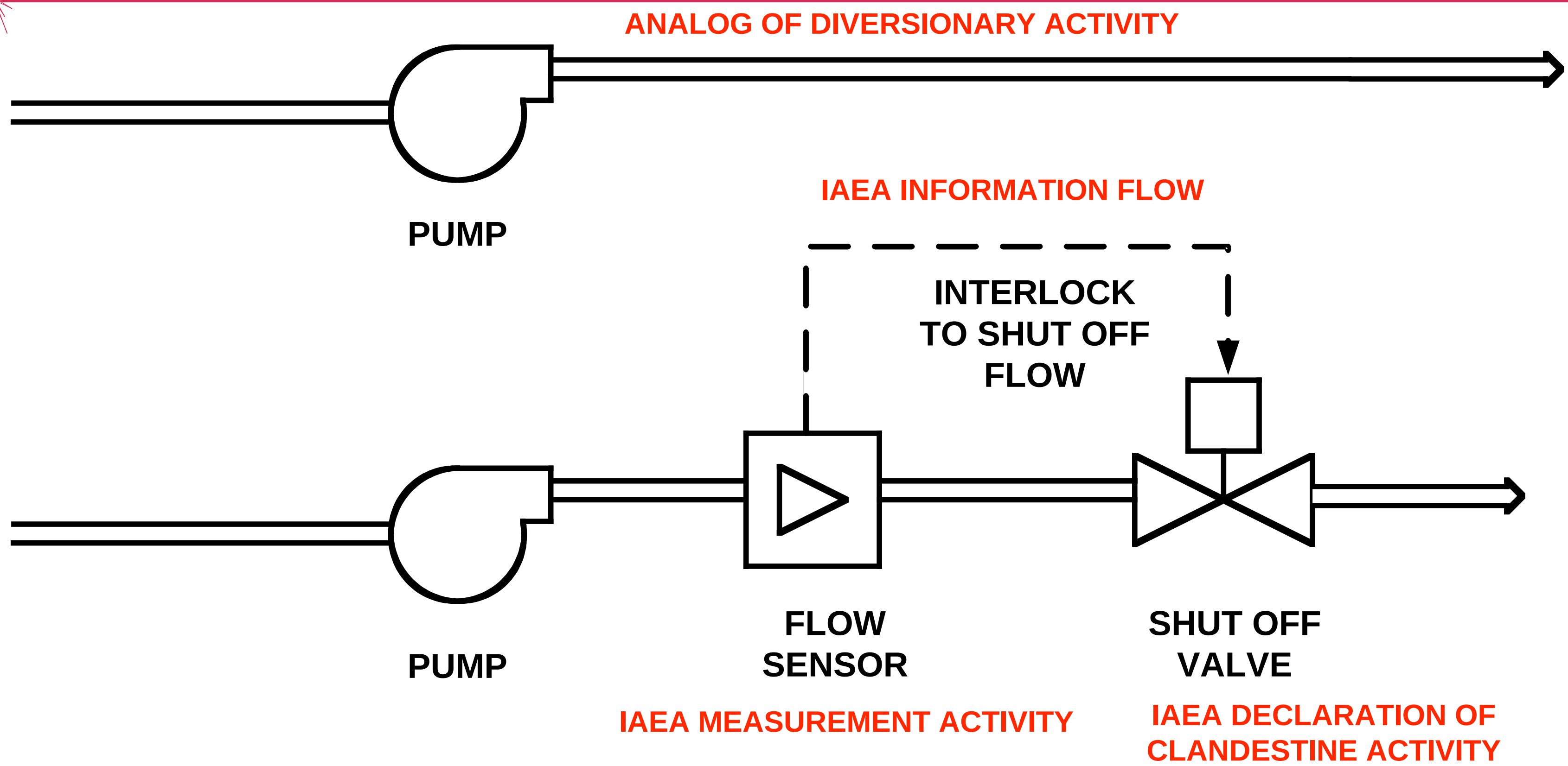
LLNL Integrated Safeguards System Analysis Tool (LISSAT)



Flow of Information Regarding Detection Paths in the Digraph

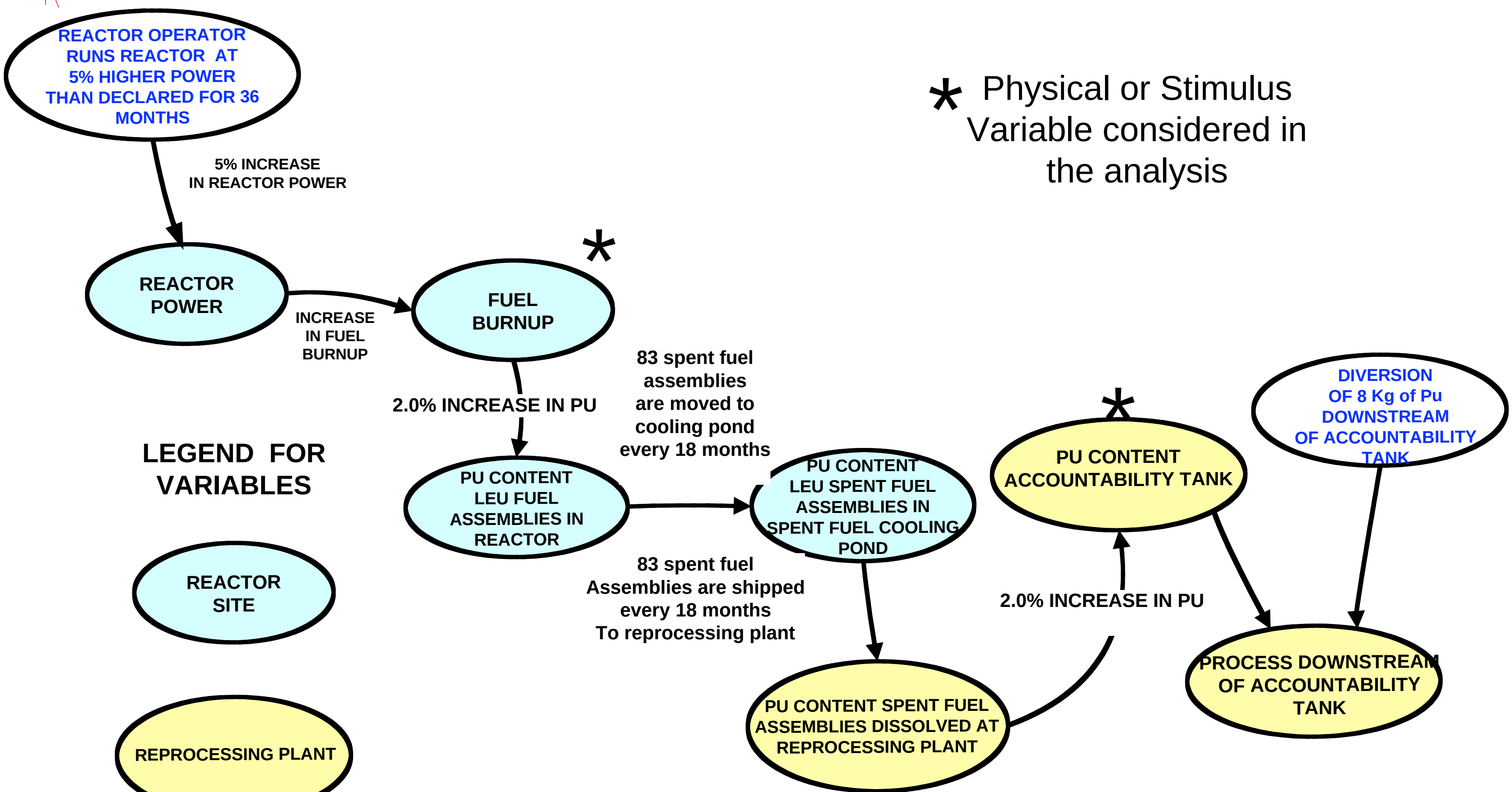


Pump System Analogy for Digraph-Fault Tree Methodology



1. **What are the diversionary activities – e.g. removal of material, concealment**
2. **How are these activities detected?**
3. **How can detection fail so that diversion goes undetected?**

Step 1 – Production of Pu at Reactor and Removal of Pu at Reprocessing Plant



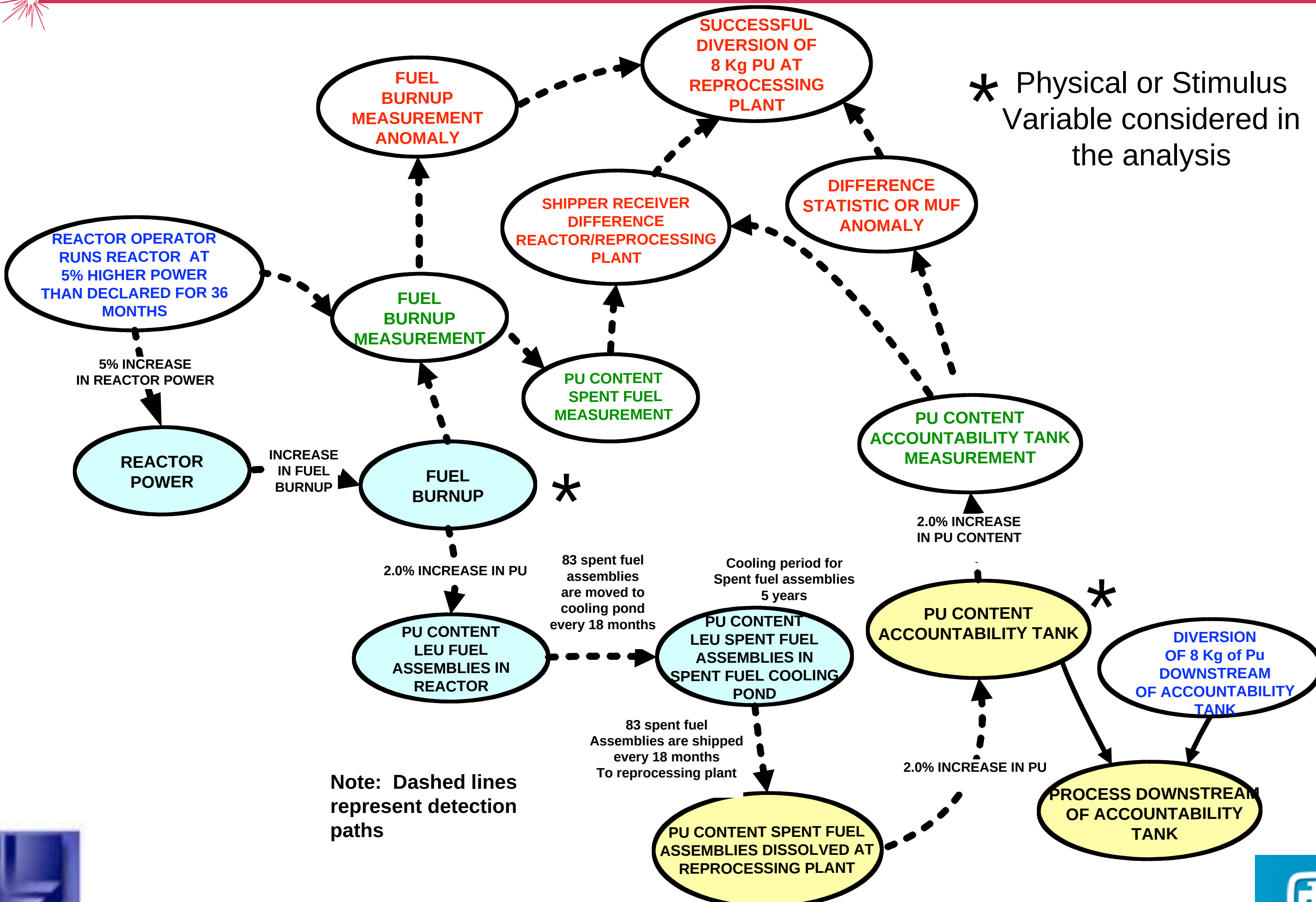
* Physical or Stimulus Variable considered in the analysis

LEGEND FOR VARIABLES

REACTOR SITE

REPROCESSING PLANT

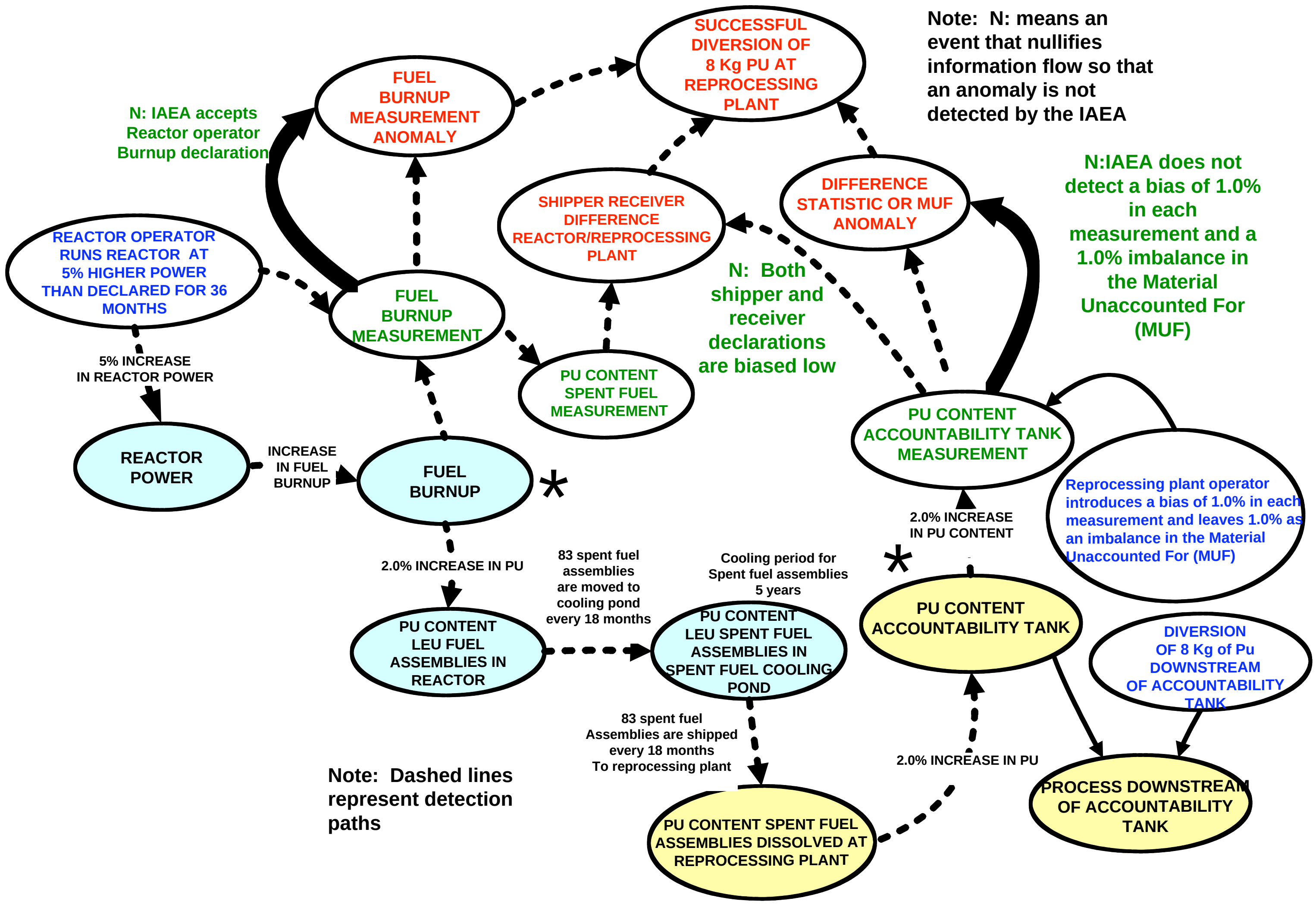
Step 2 – Include IAEA Detection Paths

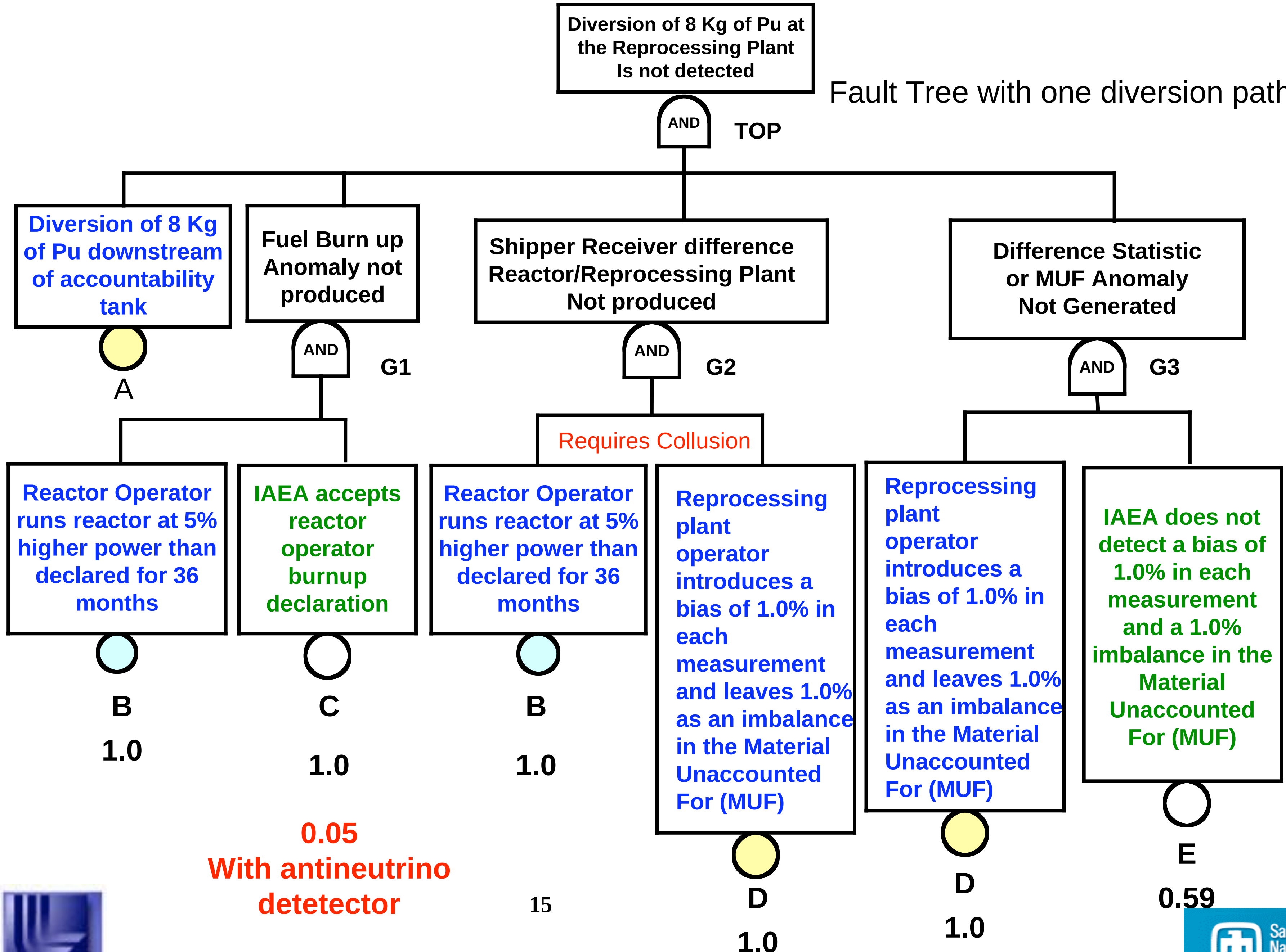


* Physical or Stimulus Variable considered in the analysis

Note: Dashed lines represent detection paths

Step 3 – Include Failures so that Anomalies are not detected




Fault Tree with one diversion path
Diversion of 8 Kg of Pu at the Reprocessing Plant Is not detected
AND
TOP
Diversion of 8 Kg of Pu downstream of accountability tank
A
Fuel Burn up Anomaly not produced
AND
G1
Shipper Receiver difference Reactor/Reprocessing Plant Not produced
AND
G2
Difference Statistic or MUF Anomaly Not Generated
AND
G3
Requires Collusion
Reactor Operator runs reactor at 5% higher power than declared for 36 months
B
1.0
IAEA accepts reactor operator burnup declaration
C
1.0
0.05
With antineutrino detetector
Reactor Operator runs reactor at 5% higher power than declared for 36 months
B
1.0
Reprocessing plant operator introduces a bias of 1.0% in each measurement and leaves 1.0% as an imbalance in the Material Unaccounted For (MUF)
D
1.0
Reprocessing plant operator introduces a bias of 1.0% in each measurement and leaves 1.0% as an imbalance in the Material Unaccounted For (MUF)
D
1.0
IAEA does not detect a bias of 1.0% in each measurement and a 1.0% imbalance in the Material Unaccounted For (MUF)
E
0.59

Diversion Path with probabilities indicated

A. Diversion of 8 kg of Pu downstream at accountability tank (1.0)

B. Reactor operator runs reactor at 5% higher power than declared for 36 months (1.0) (early detection of anomaly is possible with antineutrino detector)

C. IAEA accepts reactor operator burnup declaration corresponding to 100% reactor power (1.0) (<0.05)

D. Reprocessing plant operator introduces a bias of 1.0% in each measurement and leaves 1.0% as an imbalance in the Material Unaccounted For (MUF) (1.0)

E. IAEA does not detect a bias of 1.0% in each measurement and a 1.0% imbalance in the MUF (0.59)

Probability Reduction with Antineutrino Detector

- **Without an antineutrino detector**, the probability of nondetection is **0.59** (=Prob (Event E))

- If antineutrino detectors are employed, event C will have a lower non-detection probability. With the current prototype, the probability that the antineutrino detector will not detect a 5% reactor power increase during 36 months is <**0.05**. (=Prob(Event C))

- **With an antineutrino detector**, the probability of successful diversion probability is **<0.03** (=Prob(Event C) x Prob (Event E).

- The **reduction** in the non-detection probability is then

1/Prob(Event E) = >**20**.

Conclusions

- We are using proven systems analysis techniques for safeguards effectiveness assessment
- Generation of the diversion paths using the digraph-fault tree technique provides a systematic basis on which to assess safeguards effectiveness with and without antineutrino detectors (i.e. with current IAEA safeguards practices.)
- The preceding example is intended only to illustrate our comparison technique – further work (as described in the paper) is underway to identify additional scenarios in which antineutrino detectors may provide the most benefit