The Reactor Evaluation Through Inspection of Near-field Antineutrinos (RETINA) System

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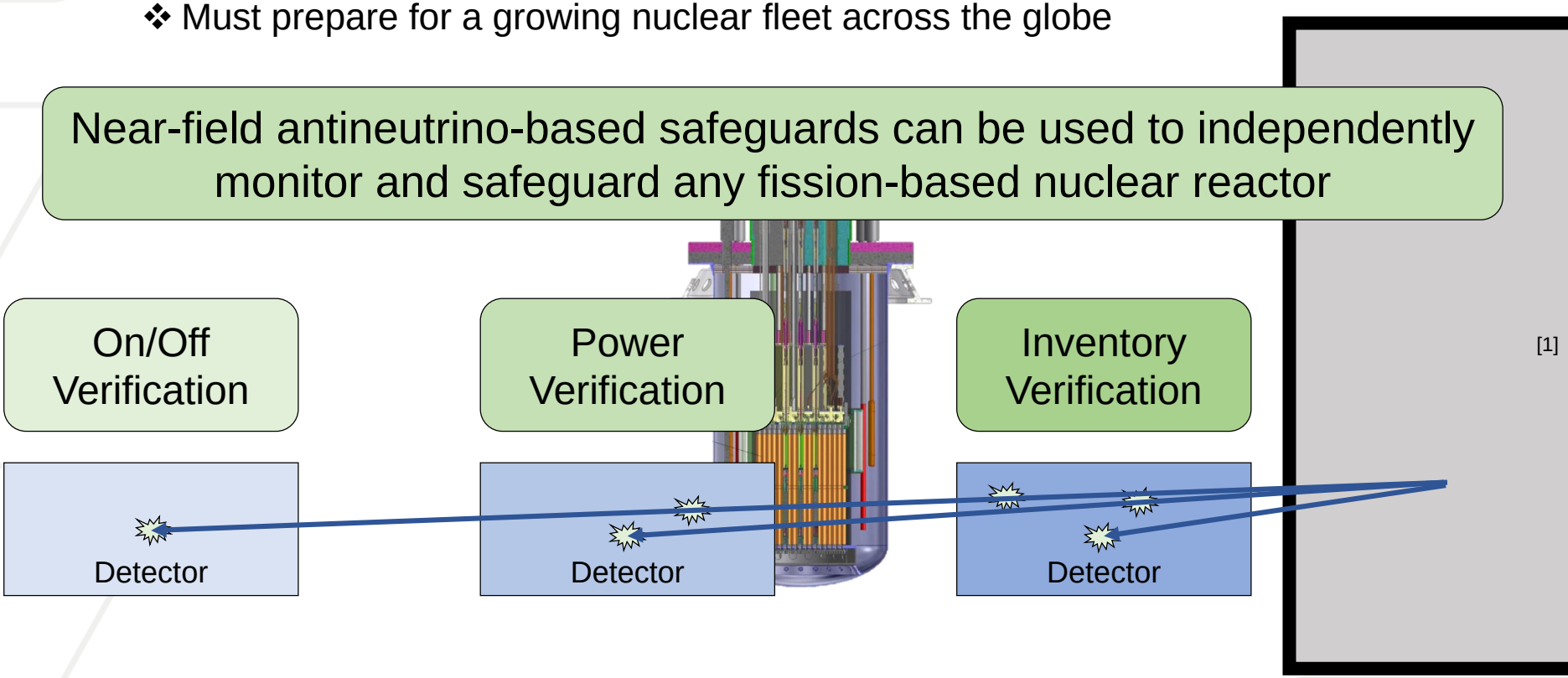
Motivation

- The International Atomic Energy Agency can effectively safeguard today's nuclear fleet
  - Must prepare for advanced nuclear reactors with unique and diverse fuel cycles
  - Must prepare for a growing nuclear fleet across the globe

Near-field antineutrino-based safeguards can be used to independently monitor and safeguard any fission-based nuclear reactor



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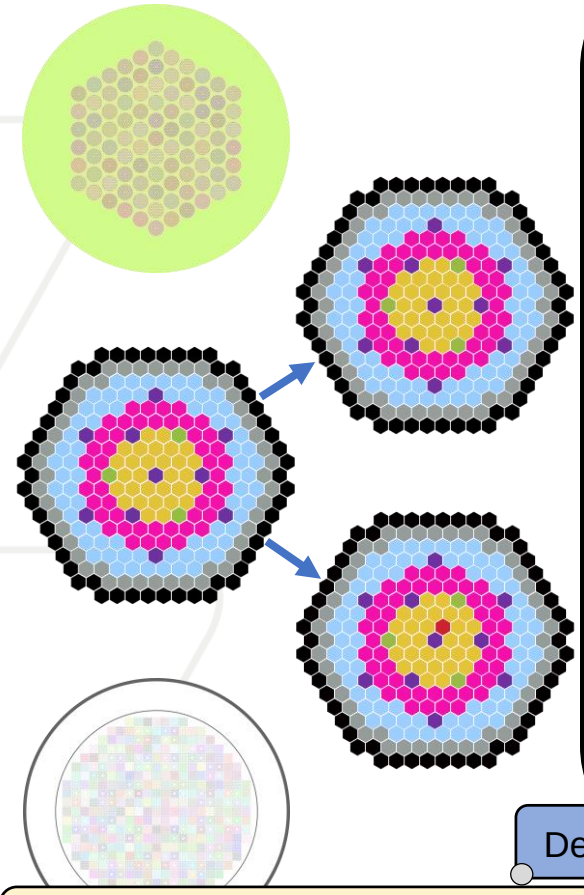
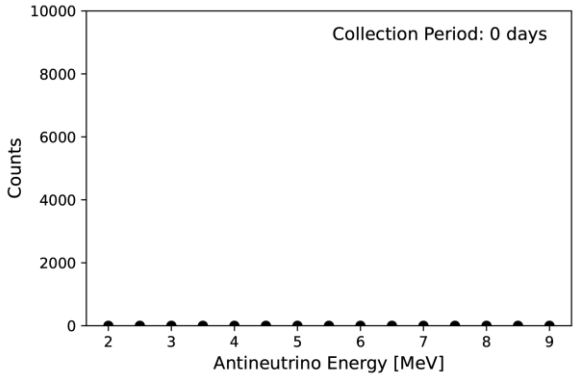
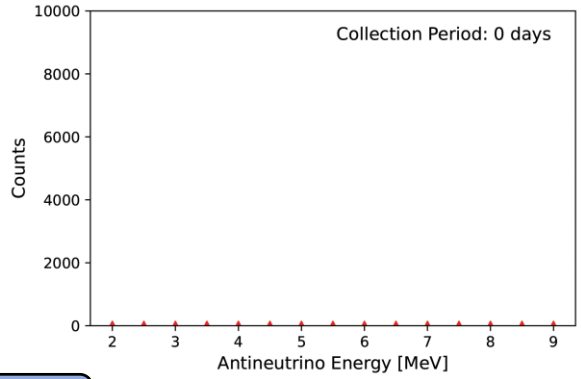
An Overview of the RETINA System

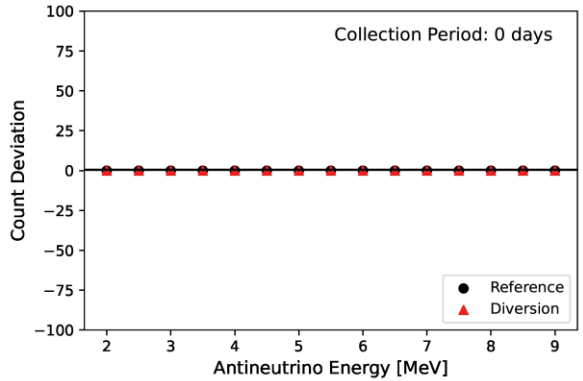
Spectra Simulation

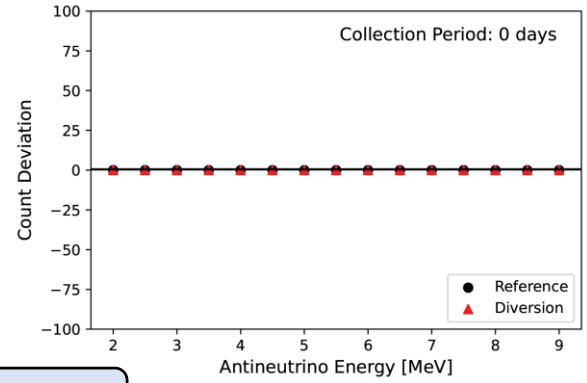
System Sensitivity











Detector

Detector

Spectra Simulation

for the RETINA System

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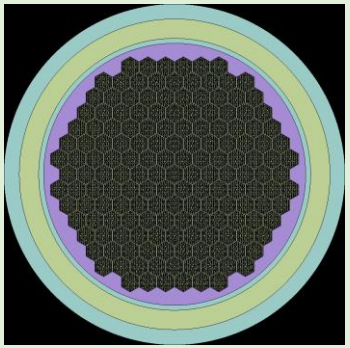
Spectra Simulation

Reactor Initialization → Detector Initialization → Scenario Simulation →

Current Capabilities

- High-fidelity reactor processing
  - SERPENT2 for isotopic fission rates and burnup calculations
  - 7 reactor designs processed
- Flexible antineutrino yield considerations
  - Only process neutrons and isotopes of interest



Potential Future Capability

- Total Monte Carlo (TMC) SERPENT2 modeling

Customize

- Reactor Design
- Burnup
- Reactor Power
- Neutron Fission Energy
- Isotopes of Interest
- Antineutrino Yield Libraries

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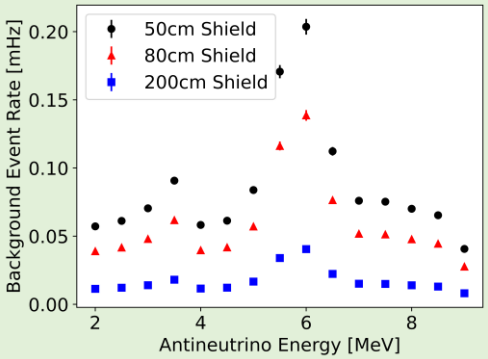
Spectra Simulation

Reactor Initialization → Detector Initialization → Scenario Simulation →

Current Capabilities

- Scalable parameters
  - Detector efficiency, size, material
- Library-based values for more complex parameters
  - Radiation background spectrum, detector efficiency, interaction cross section, detector shielding



Potential Future Capability

- Radiation background covariance matrix

Customize

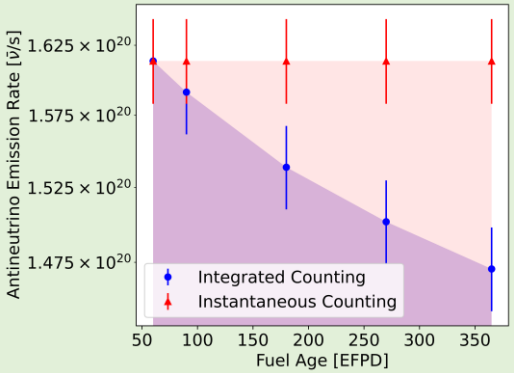
- Radiation Background Spectrum
- Detector Efficiency
- Detector Size
- Detector Proton Density
- Interaction Cross Section
- Detector Shielding

Spectra Simulation

Reactor Initialization → Detector Initialization → Scenario Simulation →

Current Capabilities

- Utilize reactor-detector configuration for a detailed scenario
  - Can alter initializations to account for more complex scenarios (e.g. six different reactor cores with six different detector standoff distances)



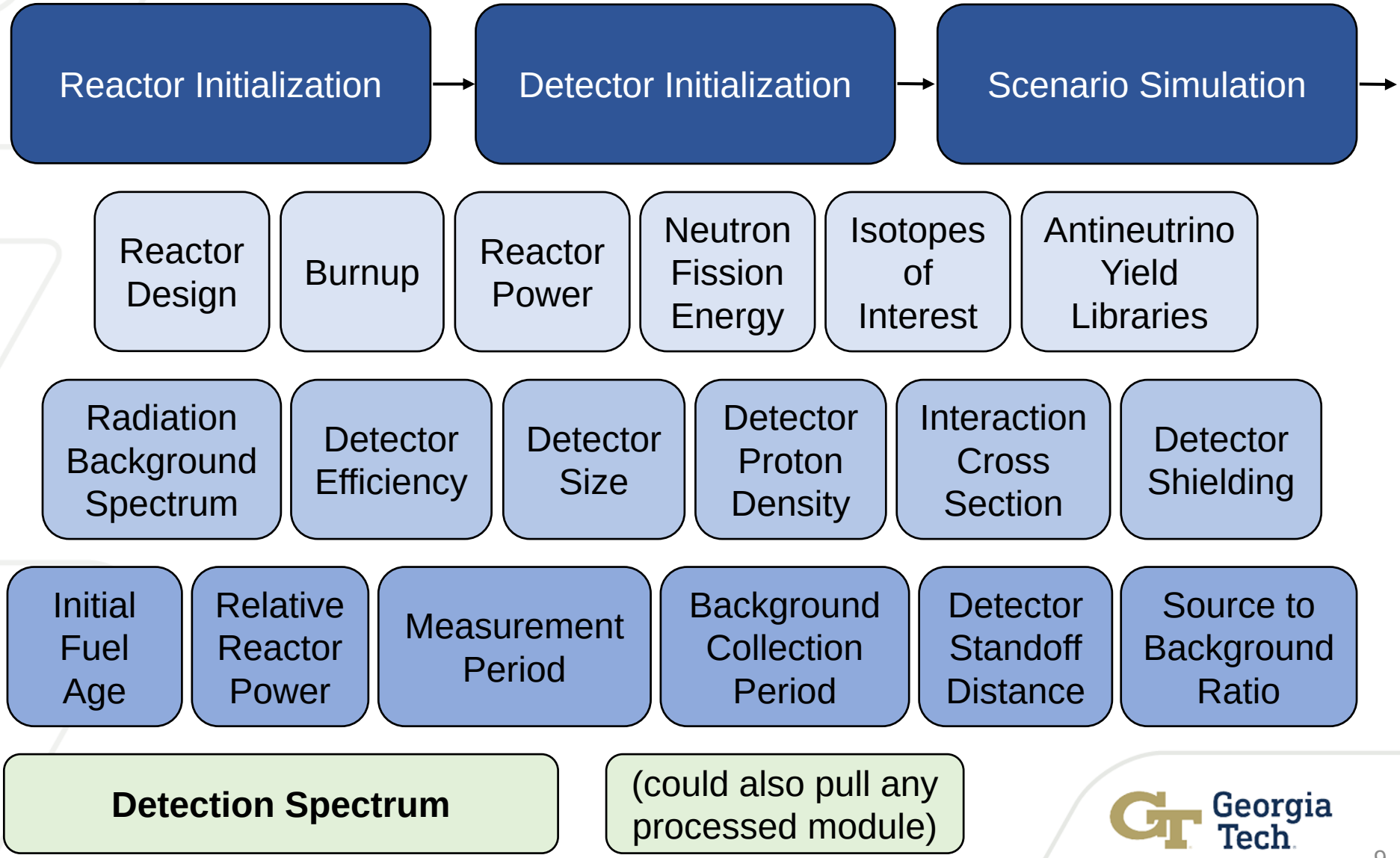
Potential Future Capability

- Graphic to represent the scenario

Customize

- Initial Fuel Age
- Relative Reactor Power
- Measurement Period
- Background Collection Period
- Detector Standoff Distance
- Source to Background Ratio

Spectra Simulation



System Sensitivity

for the RETINA System

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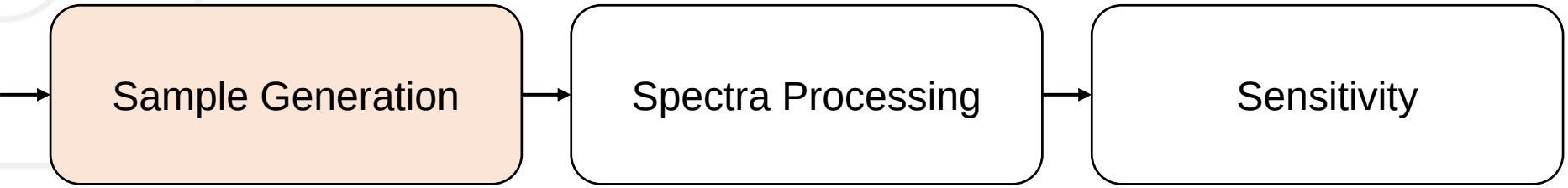
System Sensitivity



Current Capabilities

- Input initialized objects that reflect your null hypothesis and your alternative hypothesis
  - Can alter any parameter used to develop a scenario
  - The system will generate potential detection spectra (considering both Gaussian and Poisson statistics)

Potential Future Capability

- Temporal difference learning for alternative hypothesis selection

Customize

Null Detection Object
(Null Hypothesis)

Alternative Detection Object
(Alternative Hypothesis)

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System Sensitivity

Sample Generation → Spectra Processing → Sensitivity

Current Capabilities

- Build a profile to determine the likelihood (multivariant normal) of a sample belonging to one distribution and not the other

$$\lambda_0 = ln\left(\frac{\prod_{i=0}^{b} L(x_{i,0}\ \epsilon\ X_{i,0})}{\prod_{i=0}^{b} L(x_{i,0}\ \epsilon\ X_{i,1})}\right) \qquad \lambda_1 = ln\left(\frac{\prod_{i=0}^{b} L(x_{i,1}\ \epsilon\ X_{i,0})}{\prod_{i=0}^{b} L(x_{i,1}\ \epsilon\ X_{i,1})}\right)$$

- Can incorporate a background-ignorant 2-measurement scheme

Potential Future Capability

- M Reactors - N Detectors problem

Customize

Likelihood Ratio

Likelihood Ratio (2 Measurements)

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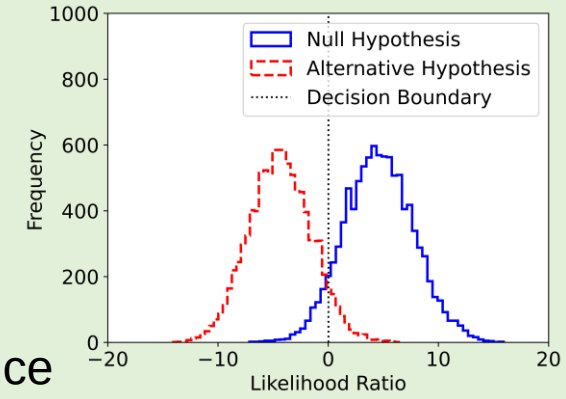
System Sensitivity

Sample Generation → Spectra Processing → Sensitivity

Current Capabilities

- Duration-based sensitivity
  - Iterate over measurement durations until we find the shortest collection period required for verification
  - Scalable gradient descent method for quick convergence
  - Custom allowable false negative and false positive rates



Potential Future Capability

- Probability-based sensitivity
- Boundary-based sensitivity

Customize

Profile Construction

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System Sensitivity

Null Detection Object
(Null Hypothesis)

Alternative Detection Object
(Alternative Hypothesis)

Likelihood Ratio

Likelihood Ratio
(2 Measurements)

Profile Construction

Measurement Period

(could also pull the spectra for the corresponding period)

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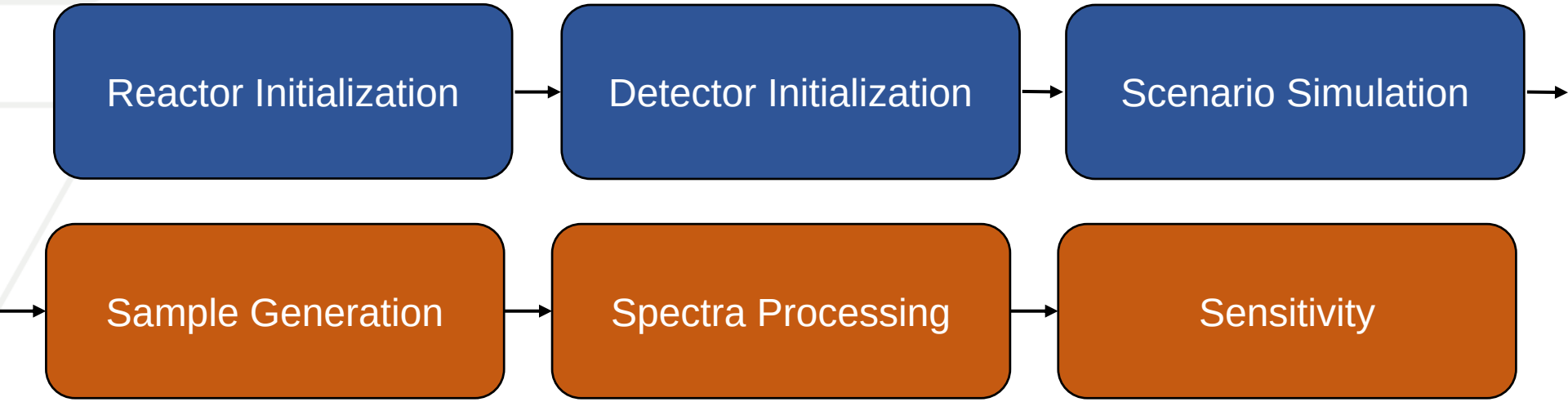
Future Work

We have well defined reactor models and detector parameters



But we still need a better idea of useful scenarios and sensitivities for the International Atomic Energy Agency

Overview of Novel Technologies and Challenges for Safeguarding Advanced Nuclear Reactors

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Acknowledgements

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Thank you

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