State of the art of Monte Carlo technics
for reliable activated waste evaluations

Matthieu Culioli, Samuel Barbier, Nicolas Chapoutier
(Areva, France), Sylvain Janski (EDF, France)
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• Source and geometry modeling

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Context

• Early characterization brings forth issues and potential challenges...
  – Impacts the cost
  – Defines the decommissioning scenario
  – Allows for optimization

• In France, ~186 000 tons of radioactive waste from the decommissioning of 9 EDF 1st generation power plants
  – 1 pressurized water reactor
  – 1 heavy water reactor
  – 6 natural uranium gas cooled reactors
  – 1 fast breeder reactor
Context

- Safety demonstration of disposal sites (existing and future) tells the level of detail needed to use those facilities
- Radioactive waste management needs a precise characterization of the radioactive inventory

activity and radio-toxicity of 143 radionuclides

- EDF uses a calculation method coupling sampling and numerical calculation

Focus on the numerical calculation
Overview

EDF’s numerical simulation method used to calculate the activation by neutron flux

1. Monte Carlo Code solving Boltzmann equation
   - nuclear data base
   - cross sections

2. Code solving Bateman equations system
   - neutron flux (x,y,z,E)
   - radioactive series

3. Waste Classification
   - calculated radioactive inventory (x,y,z,t)
   - isotopic compositions
   - with impurities
   - history of irradiation conditions
   - 3 dimensional geometry
   - with no impurities
   - neutron sources at nominal power rating conditions

4. Comparisons between Calculated and Measured results
   - calculated radioactive inventory (x,y,z,t)
   - measured radioactive inventory (x,y,z,t)
   - C/M * ratios

* C/M = calculated/measured values
Overview

EDF's numerical simulation method used to calculate the activation by neutron flux

1. **Monte Carlo Code solving Boltzmann equation**
   - 3 dimensional geometry
   - isotopic compositions with no impurities
   - neutron sources at nominal power rating conditions

2. **Code solving Bateman equations system**
   - isotopic compositions with impurities
   - history of irradiation conditions

3. **Waste Classification**
   - waste classification criteria (143 activities & toxicities)

4. **Comparisons between Calculated and Measured results**
   - measured radioactive inventory ($x,y,z,t$)

"AREVA internal software (based on Monte Carlo calculations) provides inputs for EDF calculation method"

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Overview

- AREVA calculation method is based on MCNP, an international standard for particles transport applications combined with internal tools allowing:
  - High fidelity for the source modeling
  - High detailed geometry modeling
  - Advanced variance reduction methods
  - Efficient transport and depletion calculation codes coupling

- Used for many studies supporting EDF DP2D efforts to predict the activities of French shutdown reactors (1\textsuperscript{st} generation reactors)

- Made possible because of the versatility of MCNP transport code

"**Different and large spectrum ranges**"
Source and geometry modeling (1/4)

Flux calculation
Axial and radial samplings of the source in Brennolis model

• High fidelity for the source modeling
  – Axial and radial power
  – Fuel management history

“Large amount of elementary sources (hundreds to million)”
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Source and geometry modeling (2/4)

Faster model creation with high detail level

CAD geometry of Brennilis HWR

Plan and 3D geometry of CO₂ pipes

3D MCNP model of Brennilis

MCNP model

Heterogeneity preferred → localized spectrum changes

International Symposium on Preparation for Decommissioning

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Source and geometry modeling (3/4)

- 3D complete and complex geometries are inevitable to obtain accurate results

Neutron streaming and bypass

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• AREVA’s tools and internal software
  – Precise and complete geometries
  – Fast model construction
  – Input to MCNP code

"No flux discontinuity"

• Methodology inevitable to meet the high detailed requirement of Andra for the radioactive inventories

"But it can take time without the right tools"
Variance reduction methods (1/2)

- Monte Carlo calculations are time consuming if efficient variance reduction methods (or skills) are not applied.

- AREVA invested in developing and mastering hybrid variance reduction methods well incorporated in the calculation process.
Variance reduction methods (2/2)

- AREVA’s internal routine enables the generation of WW input card
  - One calculation
  - Large scale areas

Outside of the active part

- Statistical criteria met for most difficult calculation areas in short time frame

Results obtained in hours instead of weeks of calculation
The waste characterization of a full reactor challenges data storage and management requirements.

AREVA internal software allows coupling between MCNP flux calculations and activation / depletion calculation codes.

2D / 3D visualization of results.
Coupling several calculation points or MCNP neutron flux 3D meshes of scores where every cell of the mesh contains
- nuclide inventories
- waste classification indicator
- gamma source terms on user specified decay time steps

Knowledge of material impurities contents is essential

3D considerations can lead to reducing conservatisms
- Large areas of a reactor studied
- Activation gradient calculation evaluated
Example of Chooz A PWR (1/5)

- MCNP calculation on a complex geometry
  - Peripheral assemblies modeled pin by pin
  - Internals fully described
  - Control rods out of the core
  - Concrete vessel wall up to 1m
  - Water density gradient modeled

- Neutron code source

  "Pin by pin with axial distribution"

- No material impurities in the transport calculation with MCNP
Example of Chooz A PWR (2/5)

CHOOZ A

~150 tallies

315 energy groups
Example of Chooz A PWR (3/5)

Radioactive inventory considering material impurities

Long life waste near the core

Validation of the calculation scheme
Example of Chooz A PWR (4/5)

- Validation performed with “Calculation / Measurement” ratios on standard chemical elements (Fe or Ni)
  
  high concentration, activation into large cross section range, radionuclide produced easily measured...

- Slight over-evaluation of the radioactive inventory with the numerical calculation
- Increases with the distance from the active part and linked to the structure tallied

Same trend observed about impurities and minor chemical elements
• Numerical radioactive inventory is over-estimated

• Results associated to uncertainties hardly quantified

  Measurement uncertainty, MCNP results, nuclear data uncertainty, hypothesis about irradiation history, geometry simplification hypothesis…

• But the waste classification is unchanged according to measurements

  Calculation method is validated
Conclusion and prospect

- AREVA’s expertise with Monte Carlo codes and modeling tools are an excellent application for EDF radioactive inventories.
- High detailed calculations meet Andra’s requirements more efficiently in terms of time and cost.

**Robustness of the methodology**

- Calculation scheme with MCNP and activation / depletion codes and hybrid variance reduction methods coupling with high fidelity.
  - To reduce conservatisms.
  - Validated by “C/M” ratios.
  - Now a competitive edge when it was difficult and slow a few years ago.

**Produce reliable evaluations in a short time frame**
Thank you!

Associated poster of S. Janski
“Validation of Numerical Simulations of Activation by Neutron Flux - #52923”