PREDEC
2016

International
Symposium
on PREparation
for DECommissioning

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

#A52972MC

Matthieu Culioli, Samuel Barbier, Nicolas Chapoutier (Areva, France), Sylvain Janski (EDF, France)

17th February 2016

Contents

- Context
- Overview of the calculation scheme
- Source and geometry modeling
- Variance reduction methods
- Example of Chooz A PWR
- MCNP and depletion calculation codes coupling
- Conclusion and prospect

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

Waste disposition at the CSA

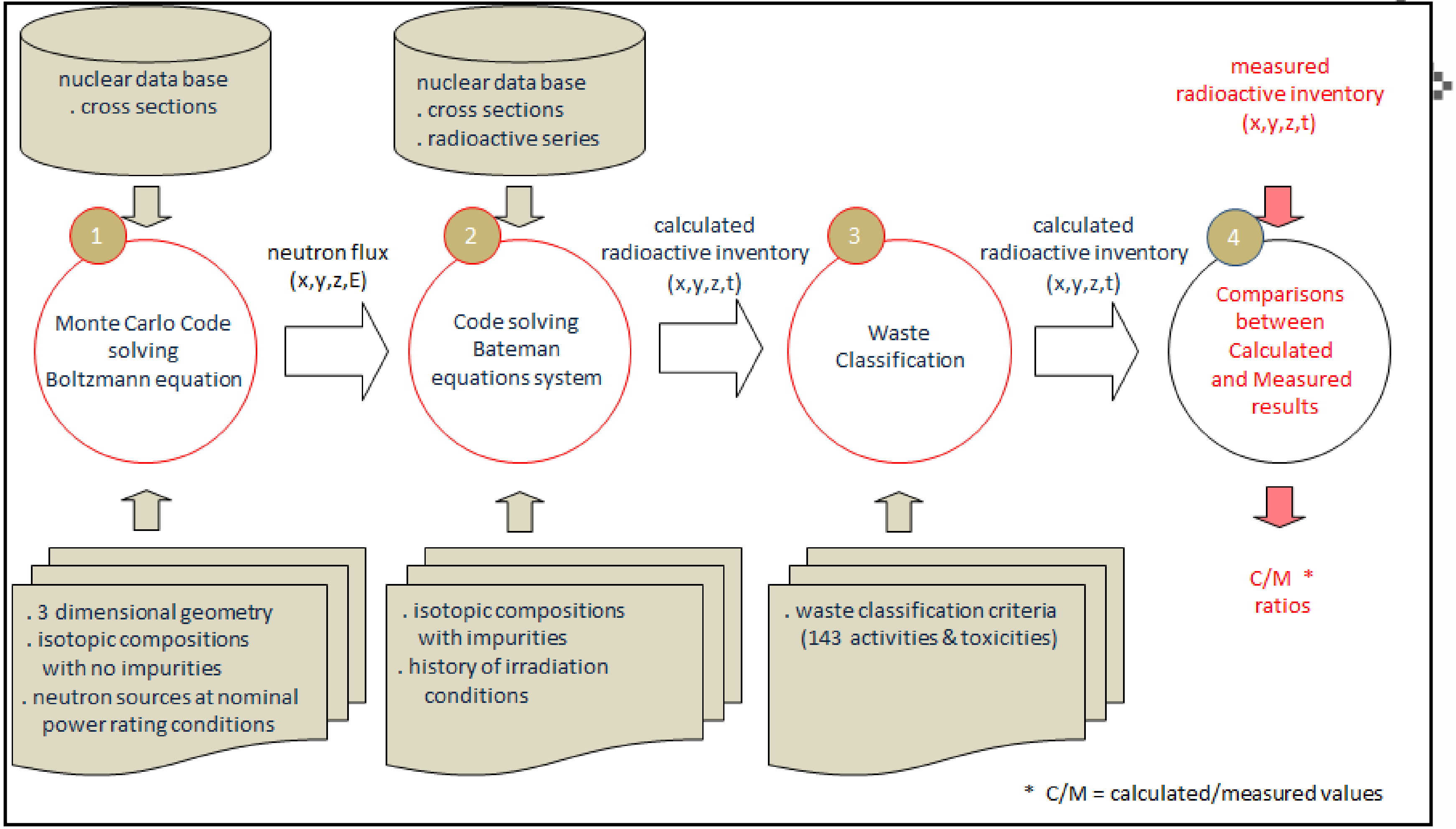
> **“ *activity and radio-toxicity of 143 radionuclides***

- 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



nuclear data base
. cross sections

nuclear data base
. cross sections
. radioactive series

measured
radioactive inventory
(x,y,z,t)

1 Monte Carlo Code solving Boltzmann equation

neutron flux
(x,y,z,E)

2 Code solving Bateman equations system

calculated
radioactive inventory
(x,y,z,t)

3 Waste Classification

calculated
radioactive inventory
(x,y,z,t)

4 Comparisons between Calculated and Measured results

. 3 dimensional geometry
. isotopic compositions
with no impurities
. neutron sources at nominal
power rating conditions

. isotopic compositions
with impurities
. history of irradiation
conditions

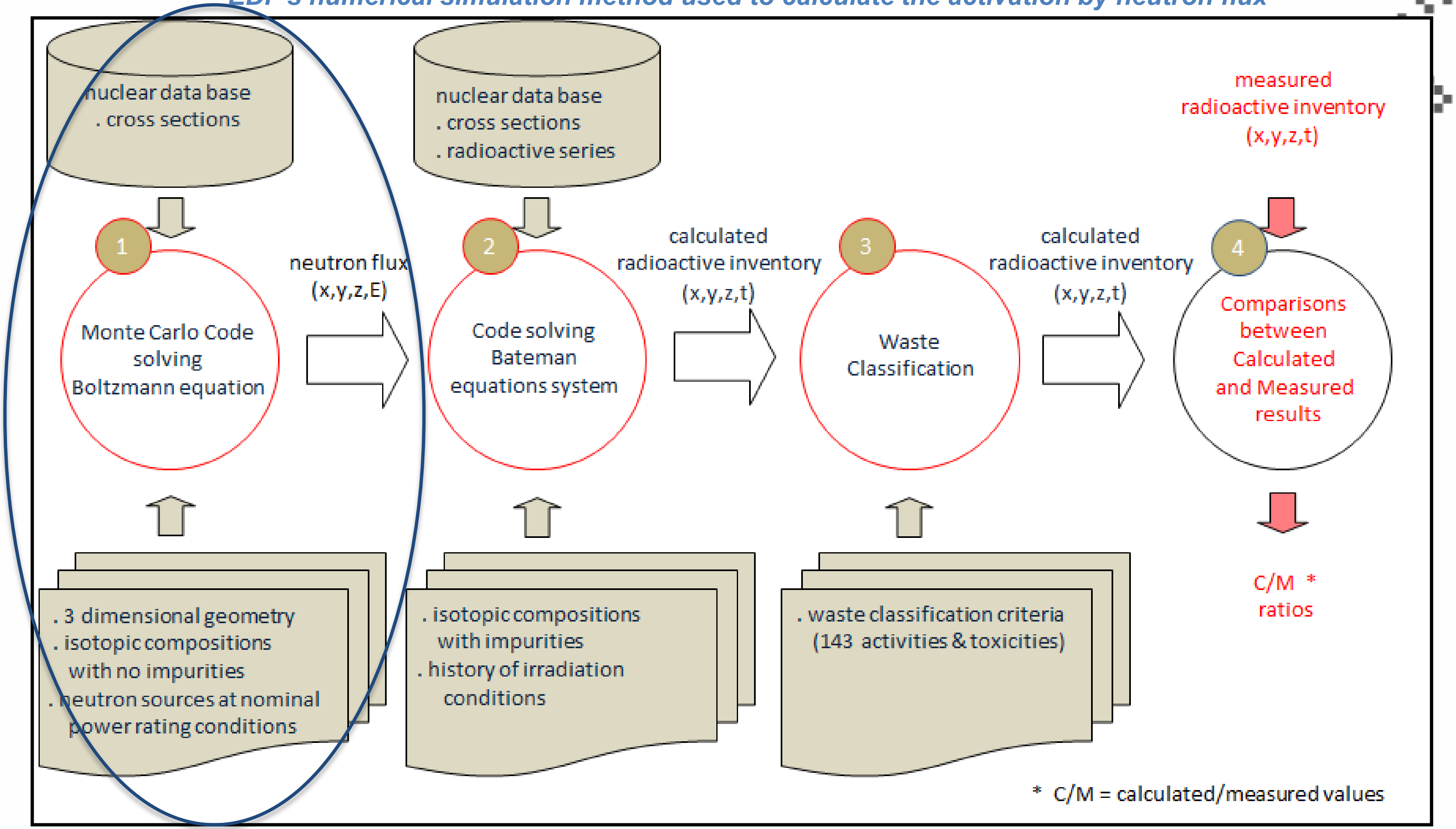
. waste classification criteria
(143 activities & toxicities)

C/M *
ratios

* C/M = calculated/measured values

Overview

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



nuclear data base
. cross sections

1 Monte Carlo Code solving Boltzmann equation

. 3 dimensional geometry
. isotopic compositions with no impurities
. neutron sources at nominal power rating conditions

neutron flux (x,y,z,E)

nuclear data base
. cross sections
. radioactive series

2 Code solving Bateman equations system

. isotopic compositions with impurities
. history of irradiation conditions

calculated radioactive inventory (x,y,z,t)

3 Waste Classification

. waste classification criteria (143 activities & toxicities)

calculated radioactive inventory (x,y,z,t)

measured radioactive inventory (x,y,z,t)

4 Comparisons between Calculated and Measured results

C/M * ratios

* C/M = calculated/measured values

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

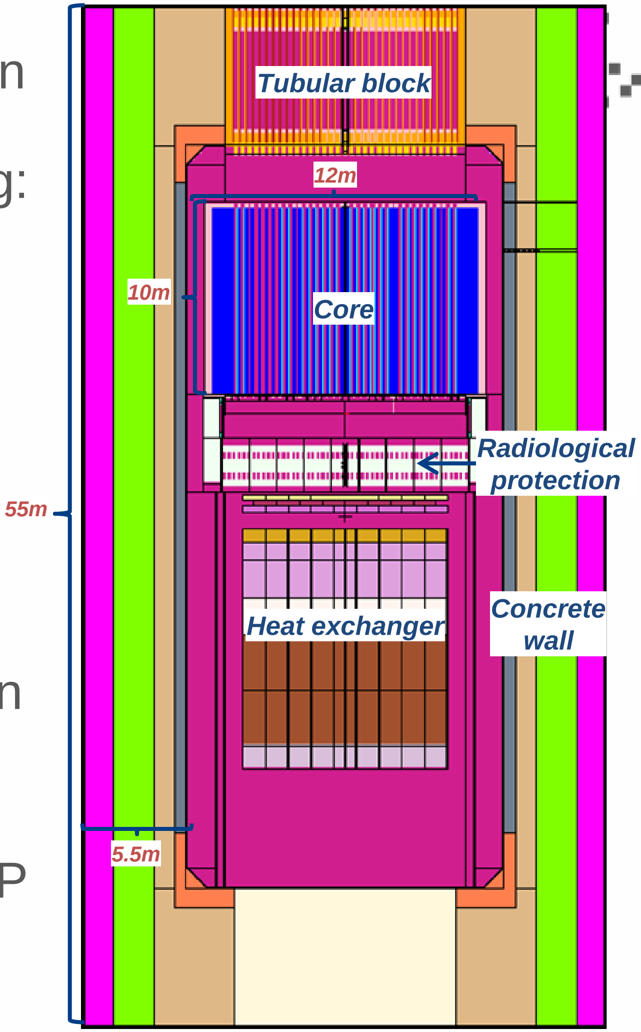
Overview

- 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^{st} generation reactors)

- Made possible because of the versatility of MCNP transport code

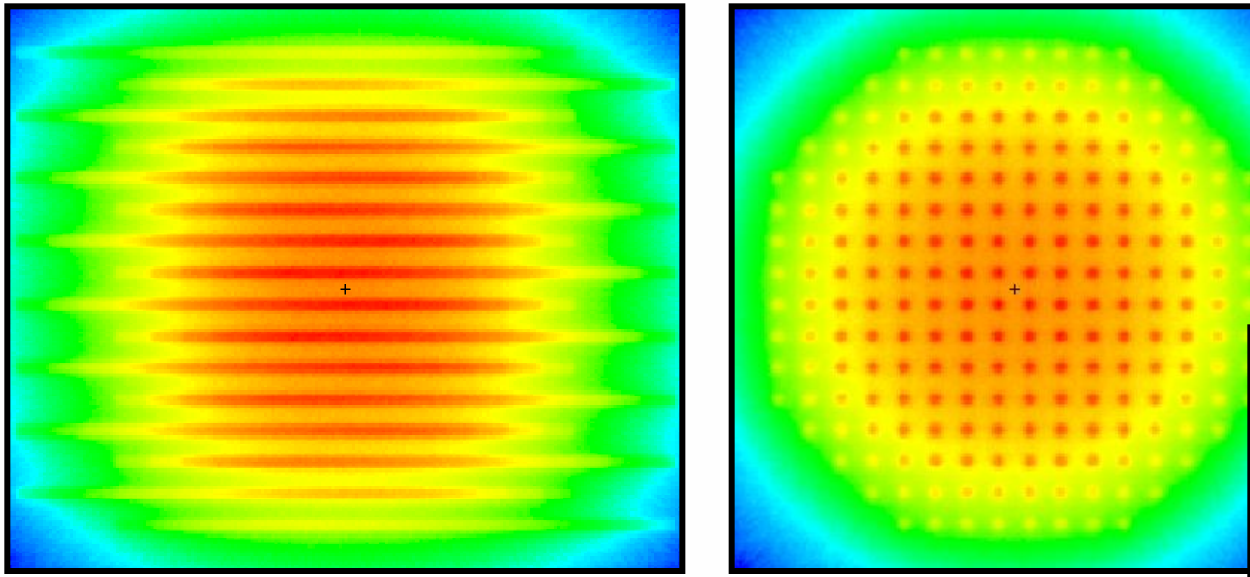
Different and large spectrum ranges

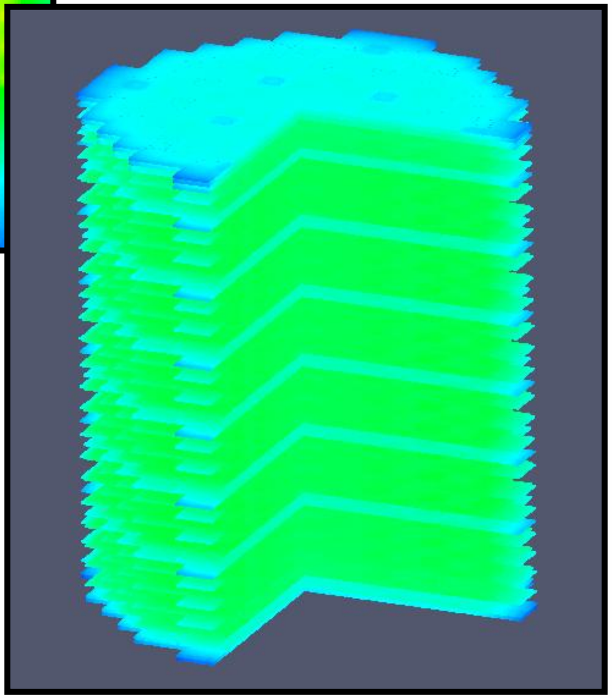


MCNP model of Bugey UNGG

Source and geometry modeling (1/4)

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





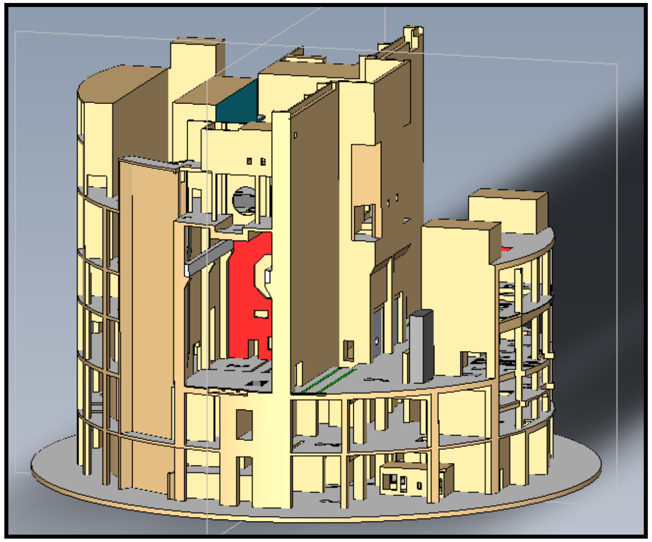
View of one type of fuel management

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

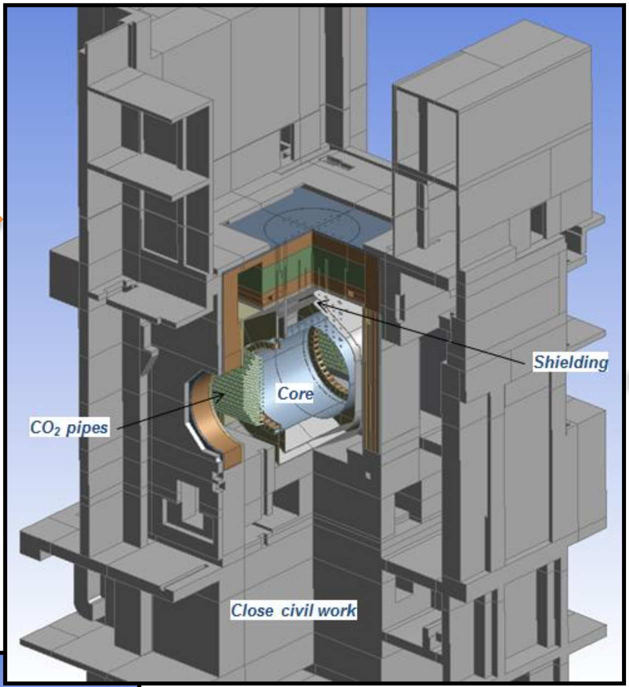
> **“*Large amount of elementary sources (hundreds to million)*”**

Source and geometry modeling (2/4)

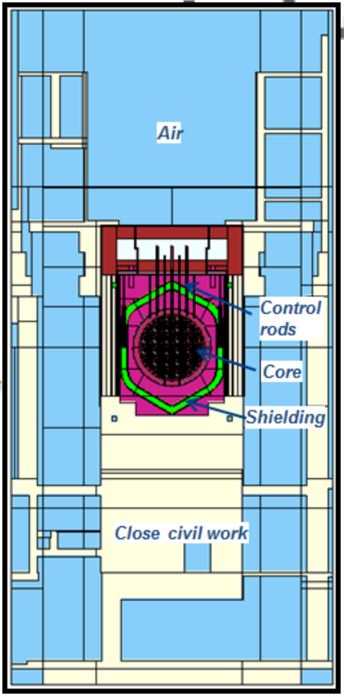
> *Faster model creation with high detail level*



CAD geometry of Brennilis HWR

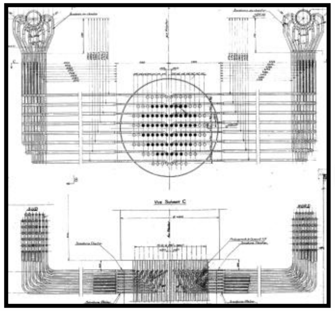


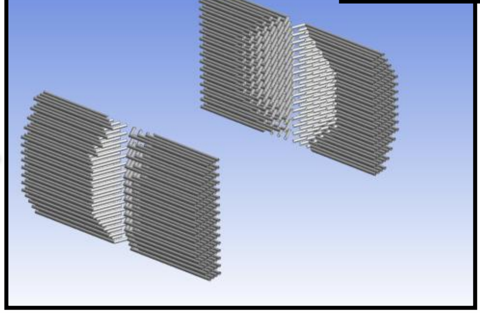
3D MCNP model of Brennilis



MCNP model

Plan and 3D geometry of CO_2 pipes

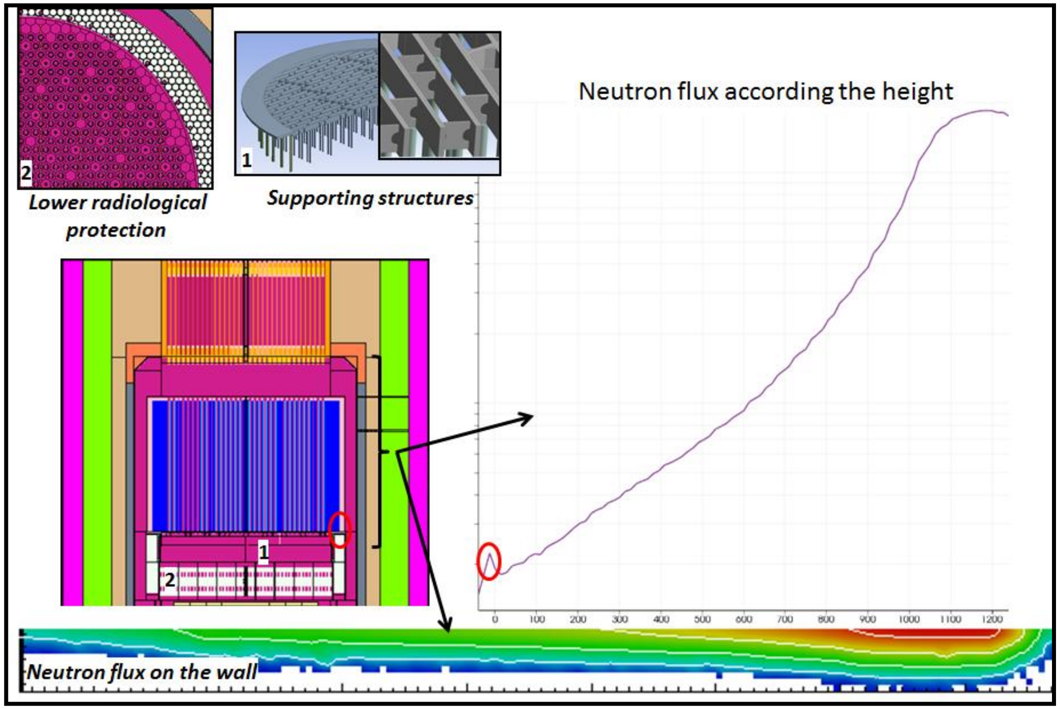


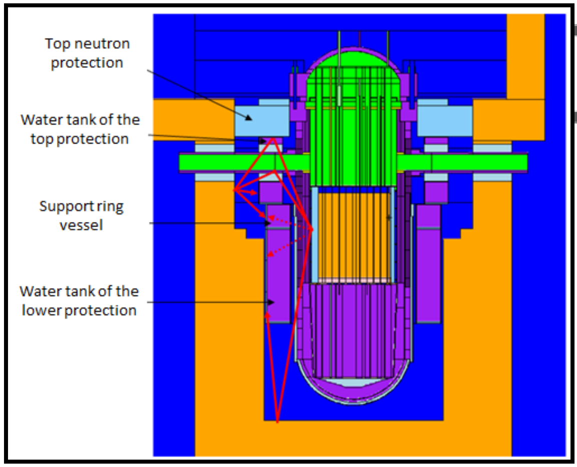


> *Heterogeneity preferred → localized spectrum changes*

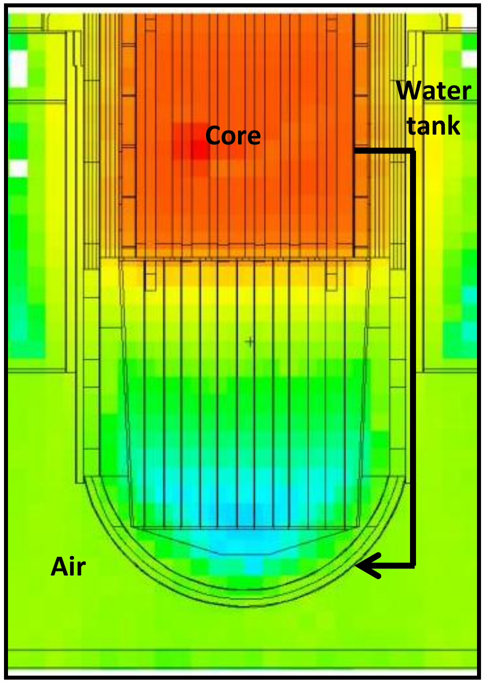
Source and geometry modeling (3/4)

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




Top neutron protection
Water tank of the top protection
Support ring vessel
Water tank of the lower protection

Neutron pathways on Chooz A PWR



> ***Neutron streaming and bypass***

Source and geometry modeling (4/4)

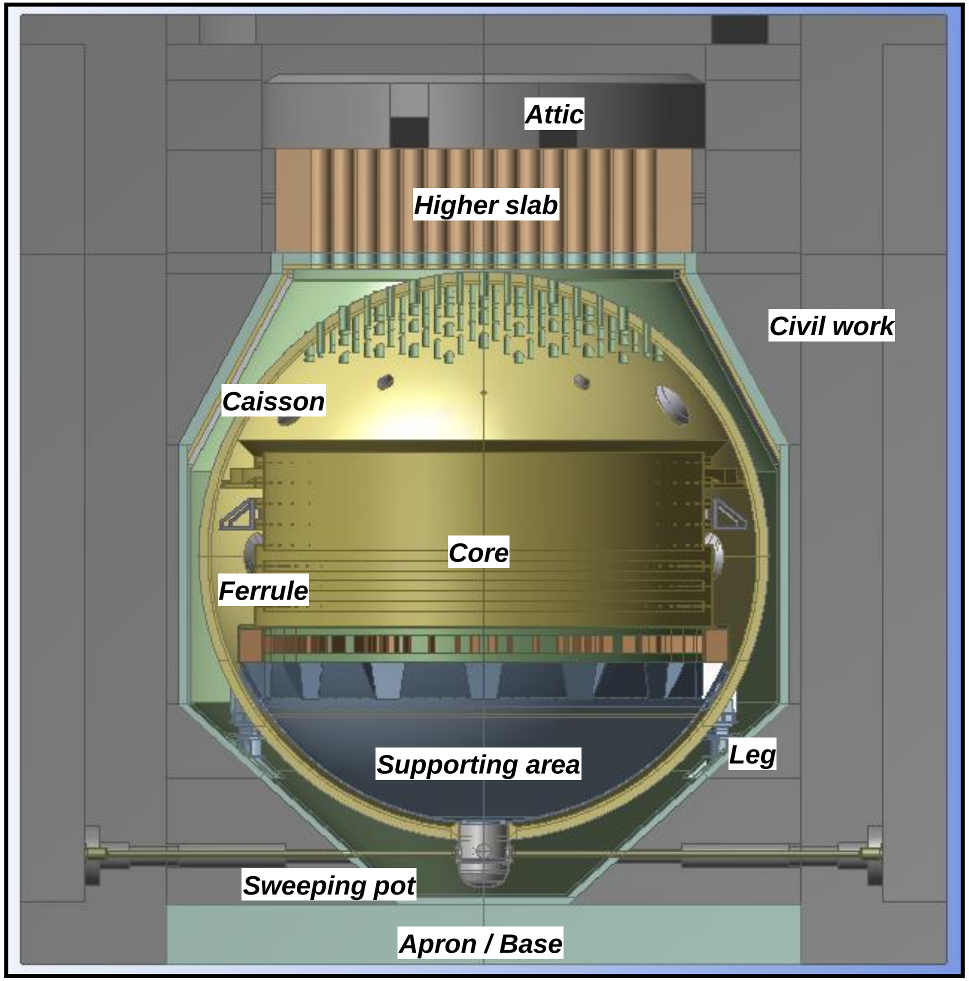
- AREVA's tools and internal software
  - Precise and complete geometries
  - Fast model construction
  - Input to MCNP code

> *No flux discontinuity*

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

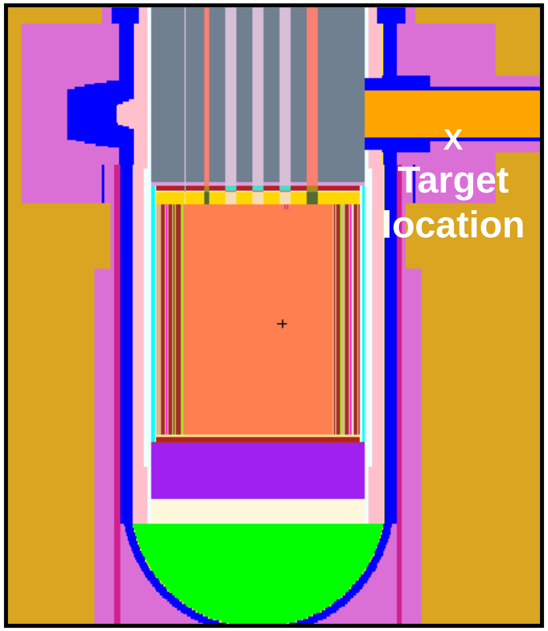
> *But it can take time without the right tools*

3D model of Chinon A2 Natural Uranium Gas Cooled



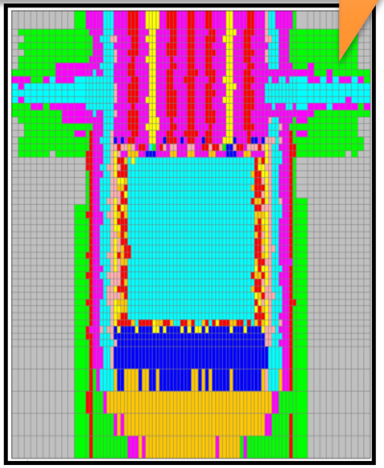
Variance reduction methods (1/2)

- 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

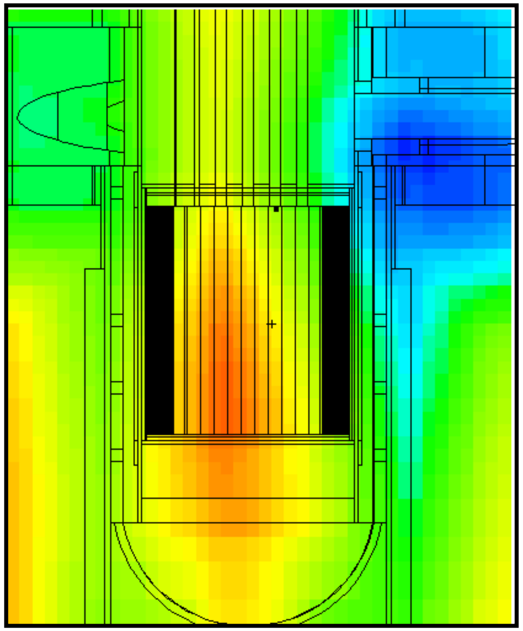


MCNP section view

Generation of WW card using CADIS method



DENOVO model



WW input card

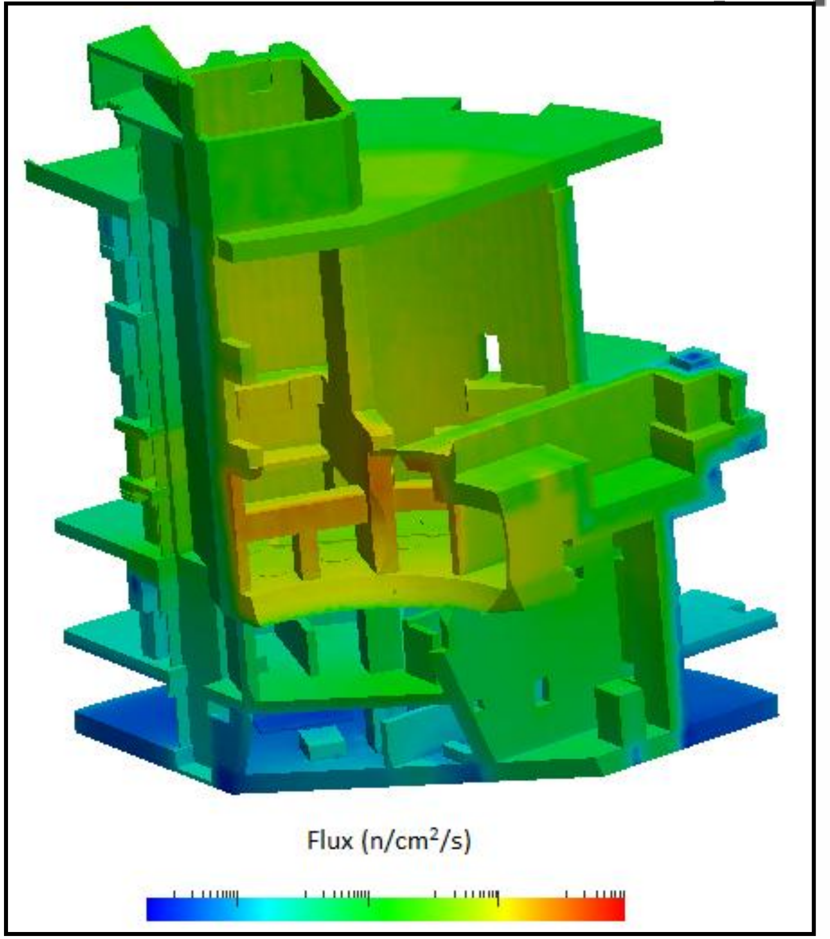
Variance reduction methods (2/2)

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

Outside of the active part

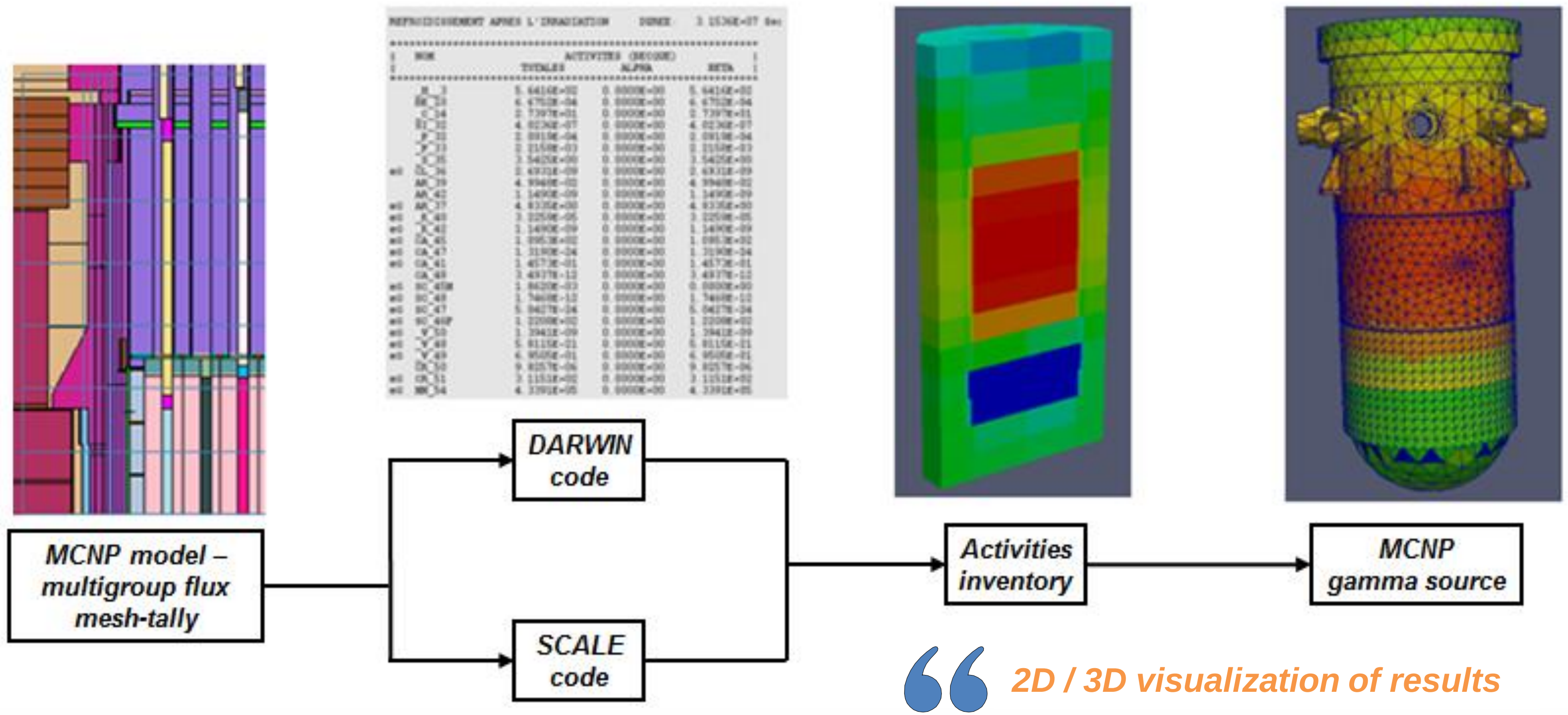
- Statistical criteria met for most difficult calculation areas in short time frame

Results obtained in hours instead of weeks of calculation



Quarter civil work of a reactor

MCNP and depletion calculation codes coupling (1/2)



MCNP model – multigroup flux mesh-tally

DARWIN code

SCALE code

Activities inventory

MCNP gamma source

2D / 3D visualization of results

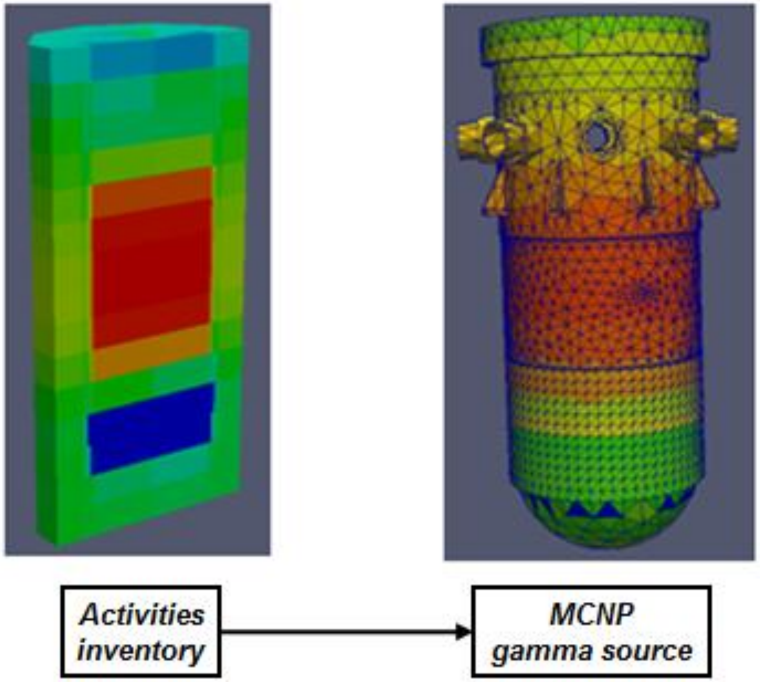
- The waste characterization of a full reactor challenges data storage and management requirements
- AREVA internal software allows coupling between MCNP flux calculations and activation / depletion calculation codes

MCNP and depletion calculation codes coupling (2/2)

- 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



Activities inventory → ***MCNP gamma source***

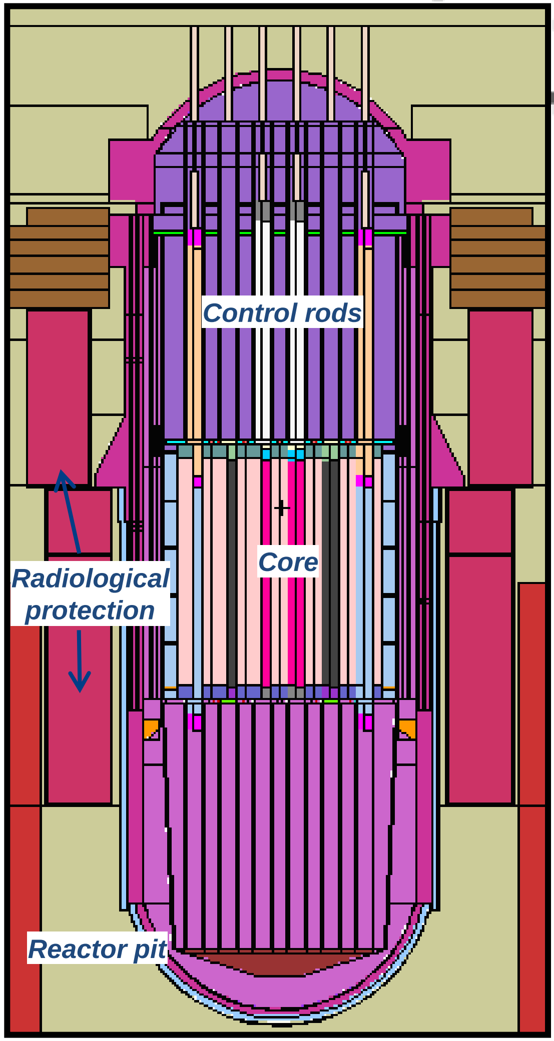
Example of Chooz A PWR (1/5)

- 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

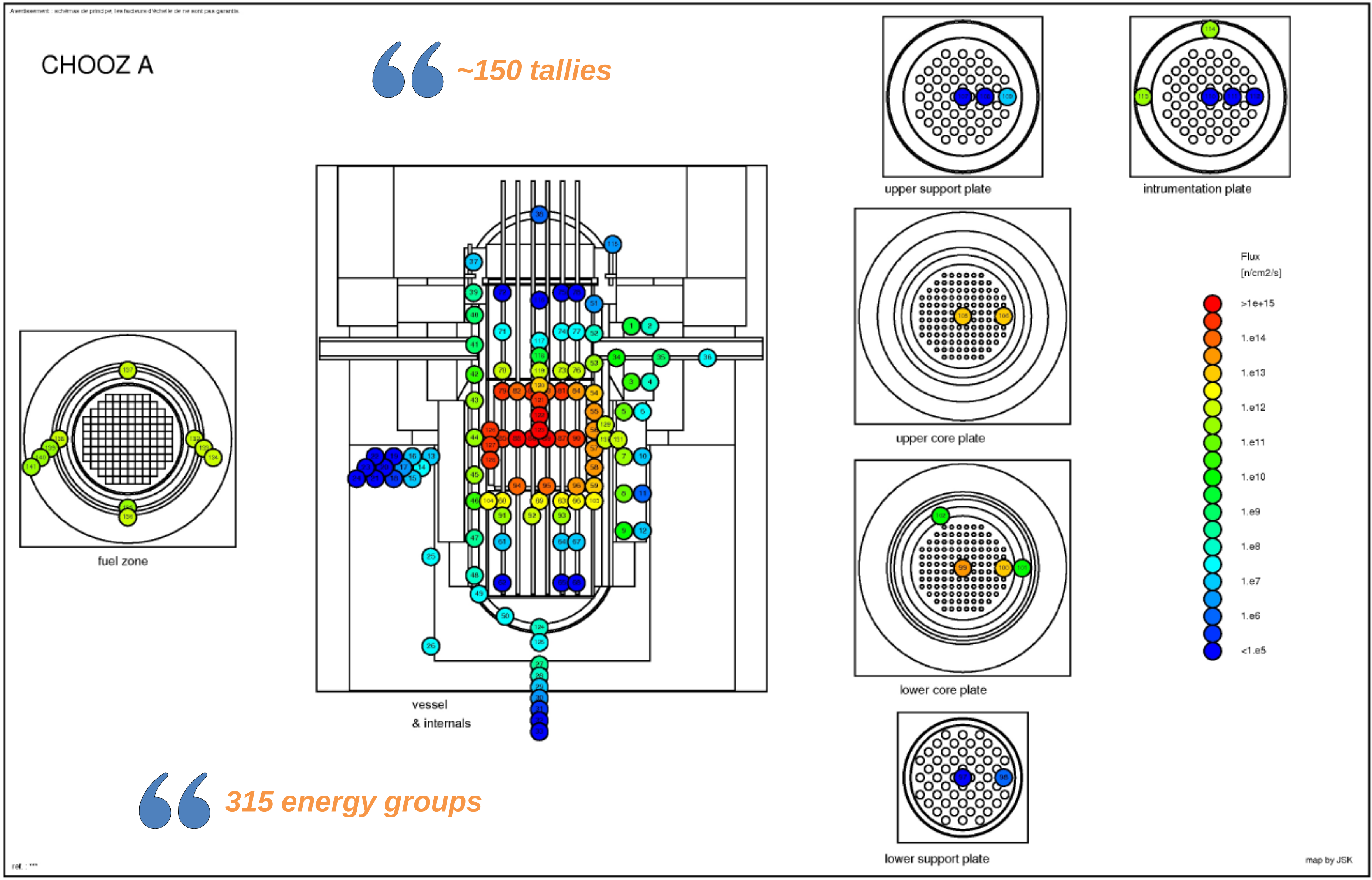
  > *Pin by pin with axial distribution*

- No material impurities in the transport calculation with MCNP



MCNP model of Chooz A PWR

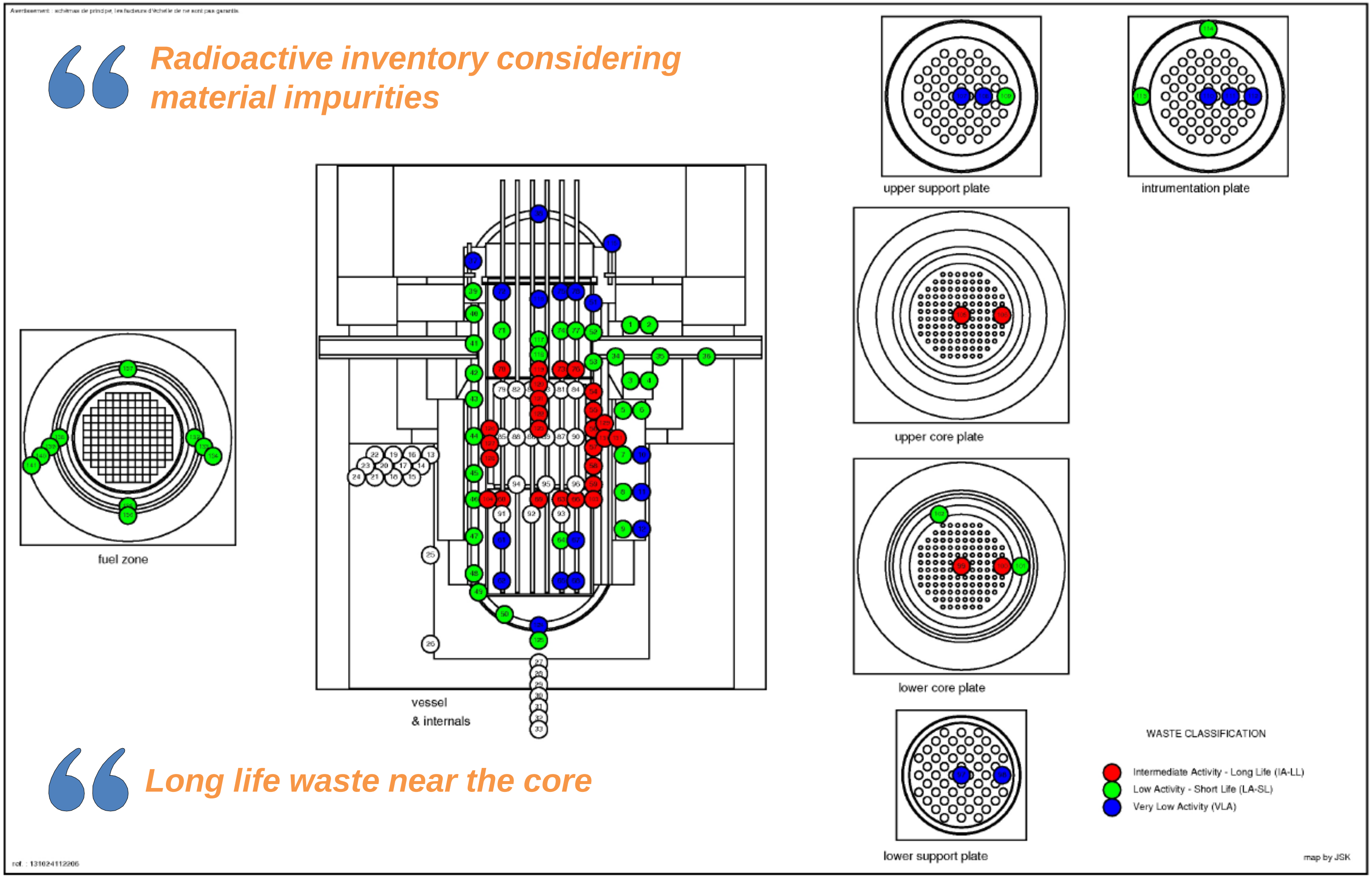
Example of Chooz A PWR (2/5)



~150 tallies

315 energy groups

Example of Chooz A PWR (3/5)


Avertissement : schémas de principe, les facteurs d'échelle ne sont pas garantis.
upper support plate
intrumentation plate
upper core plate
lower core plate
lower support plate
fuel zone
vessel
& internals
WASTE CLASSIFICATION
🔴 Intermediate Activity - Long Life (IA-LL)
🟢 Low Activity - Short Life (LA-SL)
🔵 Very Low Activity (VLA)
ref : 131024112206
map by JSK

> *Radioactive inventory considering material impurities*

> *Long life waste near the core*

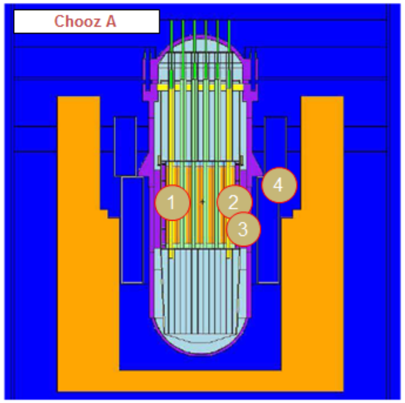
Validation of the calculation scheme

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



① internals (stainless steel)
^{55}Fe ⇨ 1.1
^{63}Ni ⇨ 1.1

② vessel coating (stainless steel)
^{55}Fe ⇨ 2.1
^{63}Ni ⇨ 2.5

③ vessel (steel)
^{55}Fe ⇨ 3.8

④ biological protection (steel)
^{55}Fe ⇨ 7.9

» ***Same trend observed about impurities and minor chemical elements***

Example of Chooz A PWR (5/5)

- 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

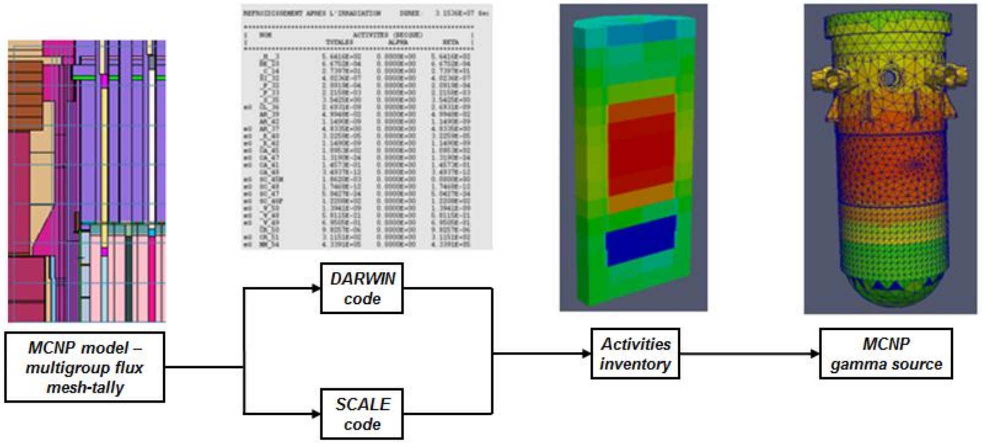
» ***Calculation method is validated***

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”