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Activation and dose rate analyses to support NPP dismantling planning

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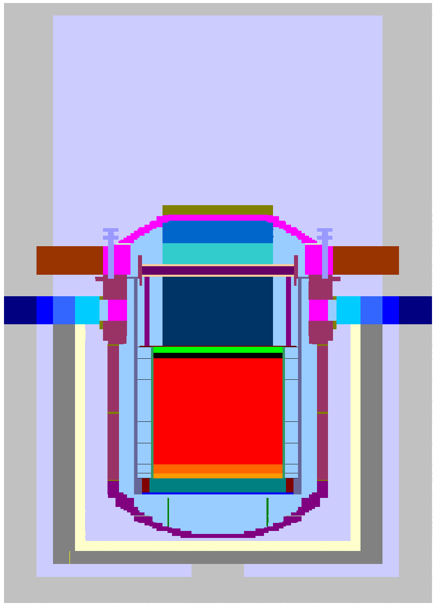
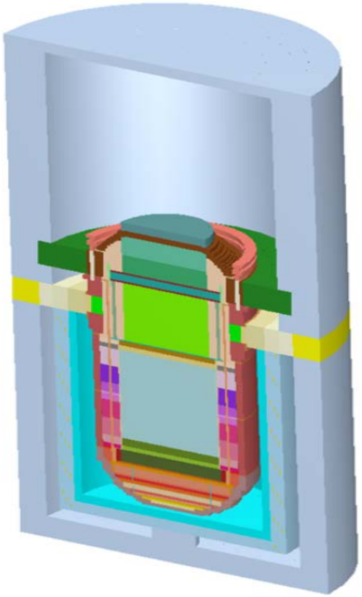
Content

- Introduction
- Benchmark: neutron flux calculation
- Activation calculation tool
- Activation calculation
- Current developments
- Conclusion

Introduction (1)

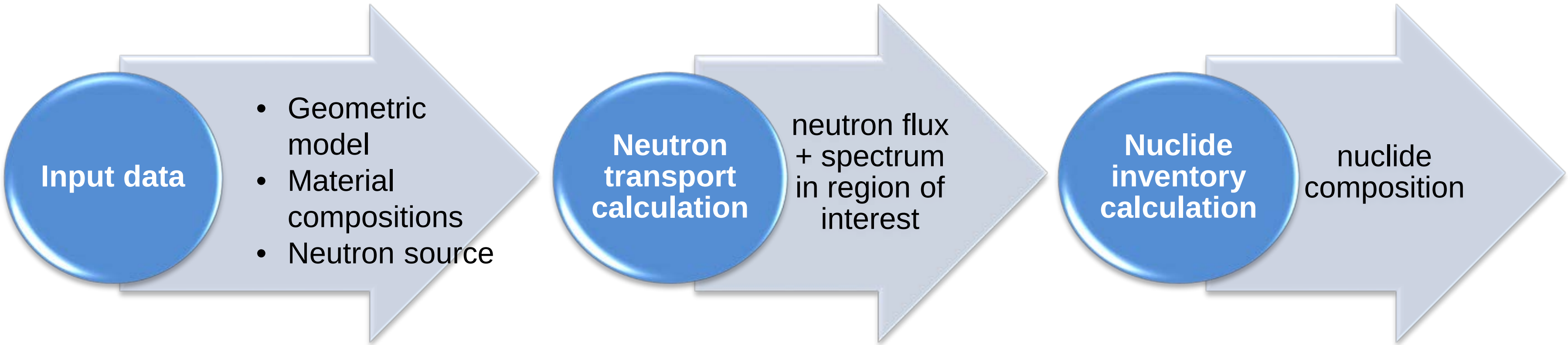
- Planning of dismantling of nuclear facility requires estimation of
  - amount of radioactive waste → treatment, conditioning, storage
  - radiation level → radiation protection measures
- Amount of activated materials can be estimated by calculations
- Previous attempt to calculate activation of reactor pressure vessel (RPV) at GRS: DORTAKTIV
- DORTAKTIV: coupling of 2d deterministic transport code DORT (r-z geometry) and ORIGEN-X





Introduction (2)

- Activation calculation:



- Deterministic transport code:
  - Advantage: complete map of neutron flux + spectrum of whole geometric model
  - Drawback: limited geometrical modeling

Activation calculation using Monte Carlo

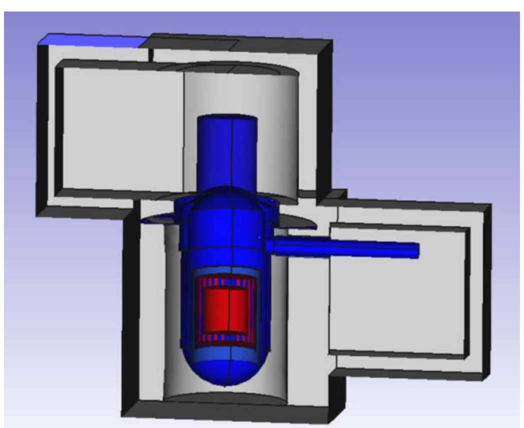
- Monte Carlo transport code:
  - Advantage: complex geometric models
  - Drawback: time-consuming calculations in case of highly shielded sources (variance reduction techniques needed)

- Current GRS activities:
  - Developed complementary activation calculation tool using Monte Carlo transport code MCNP 5
  - Test to create complex geometric models using CAD (FreeCAD 0.12)
    - Converted CAD model to MCNP (MCAM 4.8, FDS Team, China)

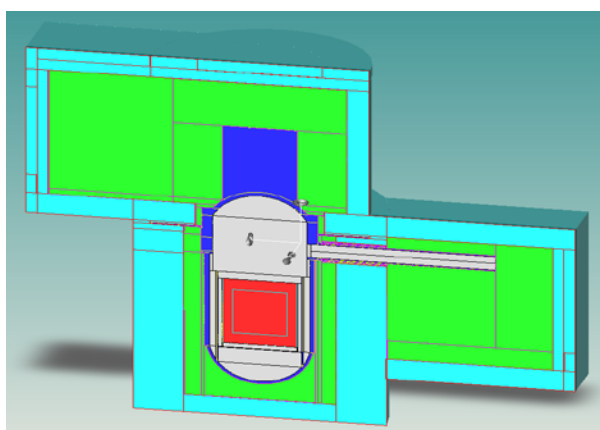
Test case: RPV benchmark model (1)

- Benchmark: evaluate characteristics + requirements of neutron transport calculations of RPV models
- Defined by NAGRA to compare neutron fluxes
- Check understanding of variance reduction techniques
  - MCNP weight windows generator (WWG)
- Modeling: CAD + conversion to MCNP ($\rightarrow$ MCAM)

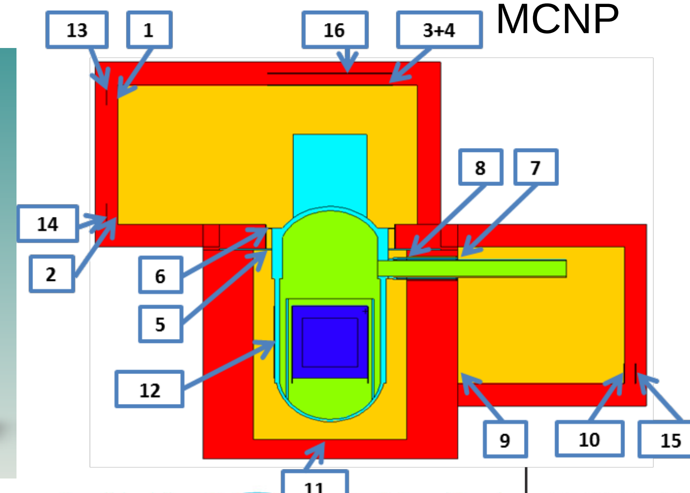
CAD



MCAM

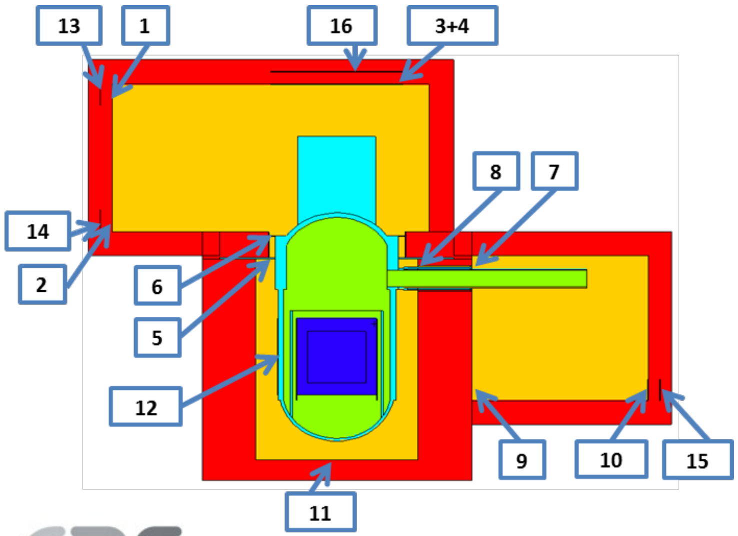


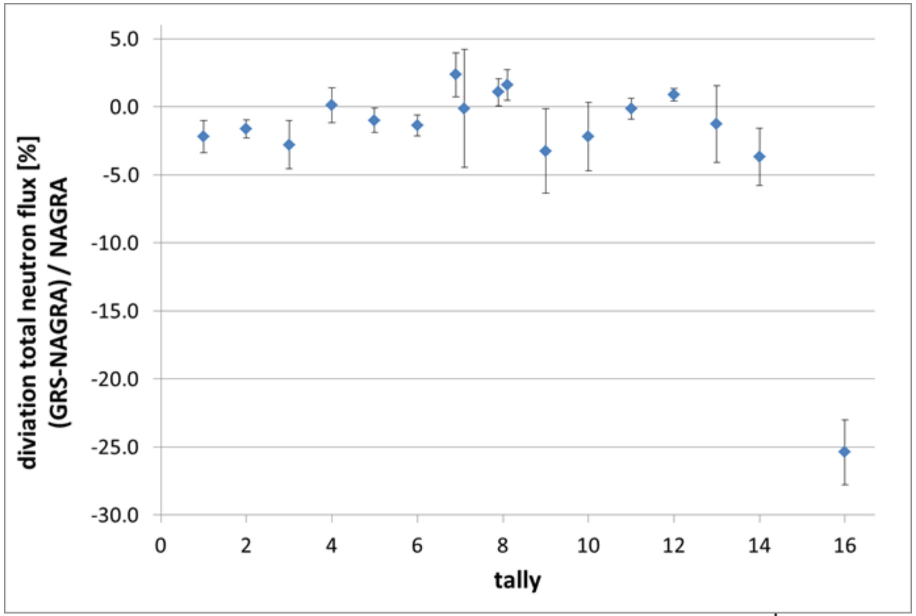
MCNP



Test case: RPV benchmark model (2)

- Compare neutron flux at 16 detector (tally) positions:
  - „perfect“ agreement for detector 1 – 14
  - No result for detector 15 (weight windows generation failed)
  - Large deviation for detector 16 (reason not found)
- In general: modeling and calculation works well



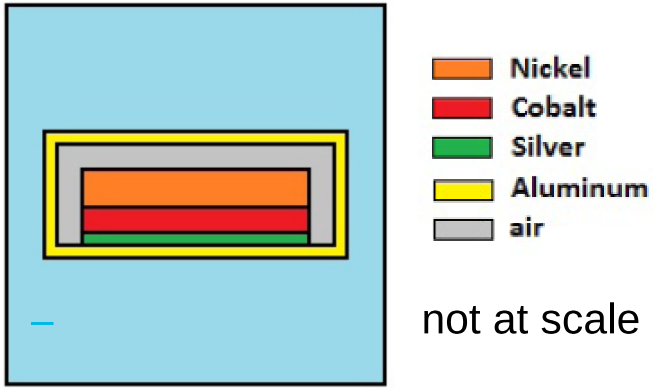


Test case: RPV benchmark model (3)

	GRS		NAGRA	
Tally	Flux [cm^{-2}/source particle]	Relative uncertainty	Flux [cm^{-2}/source particle]	Relative uncertainty
1	1,811E-14	0,0114	1,852E-14	0,0044
2	1,609E-14	0,0046	1,636E-14	0,0047
3	4,050E-14	0,0172	4,166E-14	0,0055
4	5,784E-14	0,0112	5,777E-14	0,0060
5	2,988E-12	0,0078	3,018E-12	0,0044
6	5,160E-13	0,0062	5,233E-13	0,0049
7_1	7,683E-15	0,0137	7,506E-15	0,0077
7_2	8,733E-15	0,0416	8,744E-15	0,0117
8_1	4,423E-12	0,0094	4,376E-12	0,0032
8_2	8,700E-12	0,0105	8,563E-12	0,0033
9	6,643E-17	0,0310	6,866E-17	0,0074
10	6,977E-17	0,0246	7,132E-17	0,0073
11	1,182E-11	0,0031	1,184E-11	0,0069
12	7,078E-11	0,0043	7,015E-11	0,0019
13	2,391E-16	0,0279	2,422E-16	0,0058
14	1,901E-16	0,0205	1,972E-16	0,0079
15			6.683E-19	0.0095
16	3,683E-16	0,0316	4,937E-16	0,0060

Test case: RPV benchmark model (4)

- Extending Benchmark: considering activation sample at detector position 11
  - Thin foils of Ni (0.1 mm), Co (0.025 mm) and Ag (0.01 mm), ∅ = 2cm
  - ${}^{58}_{28}Ni\ (n,p){}^{58}_{27}Co,\quad {}^{59}_{27}Co\ (n,\gamma)\ {}^{60}_{27}Co,\quad {}^{109}_{47}Ag\ (n,\gamma){}^{110m}_{47}Ag$
  - Sample included in benchmark model
  - Nuclide inventory calculated using GRSAKTIV-II
  - GRSAKTIV-II based on ORIGEN-X but handles 84 energy group fluxes
- Nuclide masses: GRSAKTIV-II and MCNP reaction rates



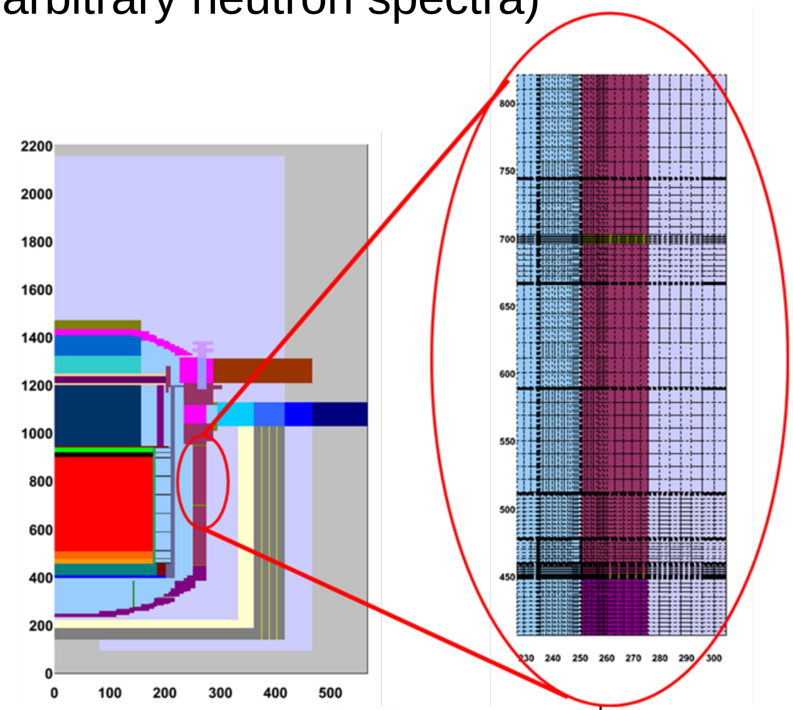
not at scale

	Nuclide mass [g]	
	MCNP reaction rates	GRSAKTIV-II
^{60}Co	3,803e-7	3,731e-7
^{110m}Ag	1,075e-8	1,419e-8
^{58}Co	1,229e-11	9,875e-12

MCNP based activation calculation tool (1)

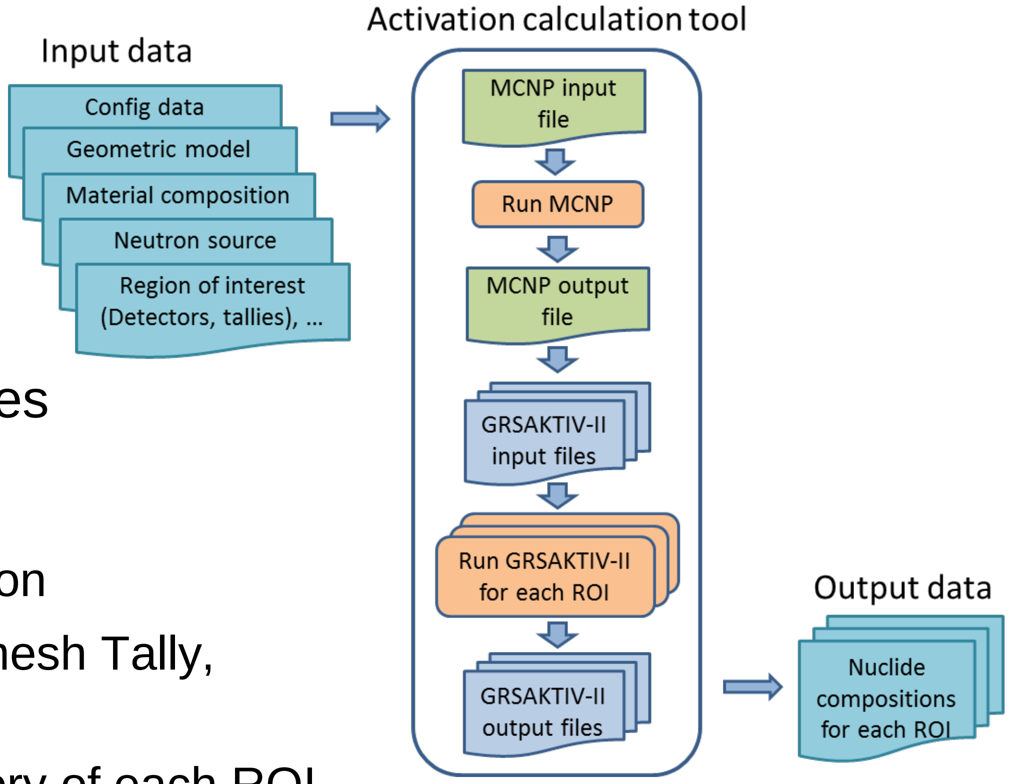
Calculation tool requirements:

- No restrictions in:
  - Geometric model (⇒ handle detailed model)
  - Nuclide inventory calculation (⇒ handle arbitrary neutron spectra)
  - Material composition
  - Source definition
- Arbitrary choice of region of interest (ROI, regions to calculate activation)
  - Segmentation of ROI (equivalent to DORTAKTIV)



MCNP based activation calculation tool (2)

- Developed activation calculation tool using:
  - Monte Carlo transport code MCNP 5
  - Nuclide inventory calculation: GRSAKTIV-II
- GRSAKTIV-II based on ORIGEN-X, but neutron fluxes in 84 energy groups to calculate nuclide inventories
- Calculation sequence:
  - MCNP: Neutron flux distribution
  - Extract neutron flux of ROI (mesh Tally, 84 energy groups)
  - GRSAKTIV-II: nuclide inventory of each ROI

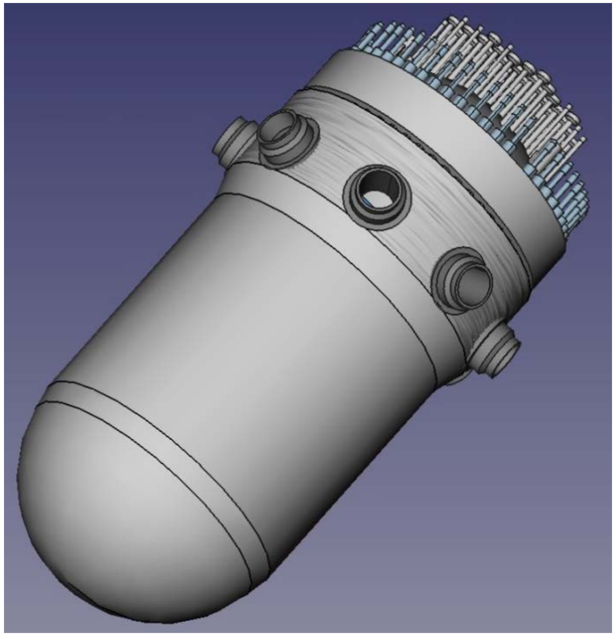


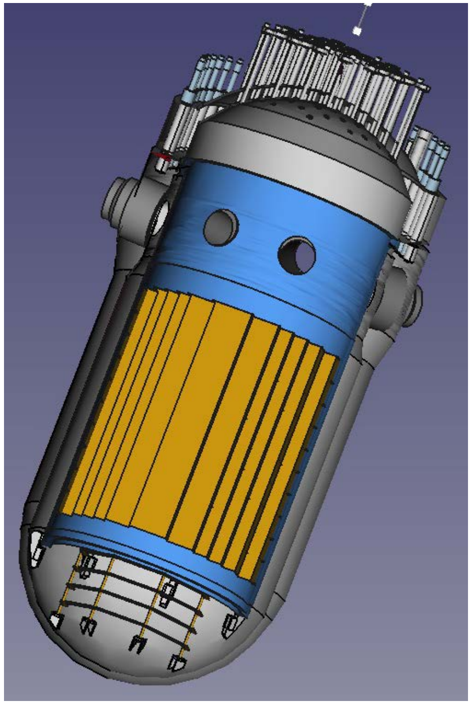
Activation calculation generic RPV (1)

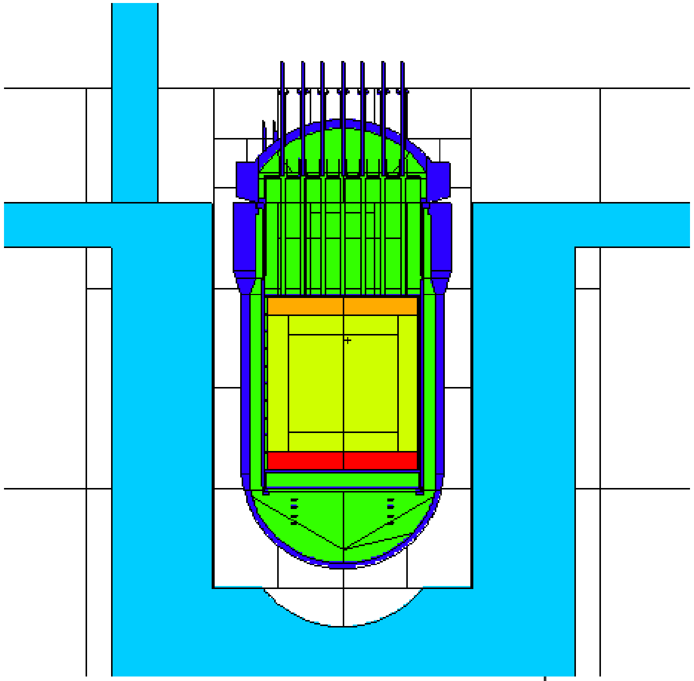
- Test case: detailed generic RPV model
  - Created geometric model using CAD (FreeCAD 0.12)
  - Converted CAD model to MCNP (MCAM 4.8, FDS Team, China)

CAD

MCNP





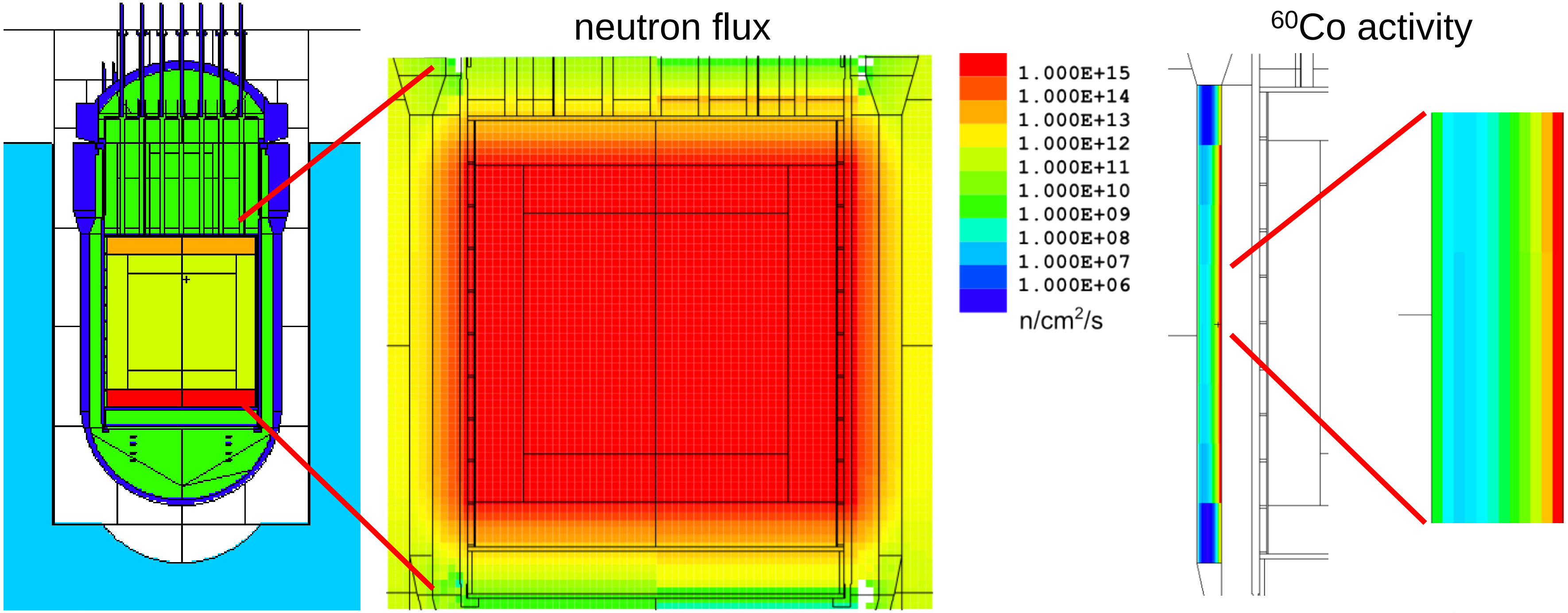


Activation calculation generic RPV (2)

- Some assumptions:
  - Homogenized neutron source (outer ~30 cm of reactor core)
  - Thermal power of 2.2 GW
  - Neutron rate of $\sim 1 \times 10^{20}$ s^{-1} (active part of the core)
  - 25 cycles: 10 month + 2 month down time
  - For example: Co impurity of the RPV steal of about 0.02 wt.-%

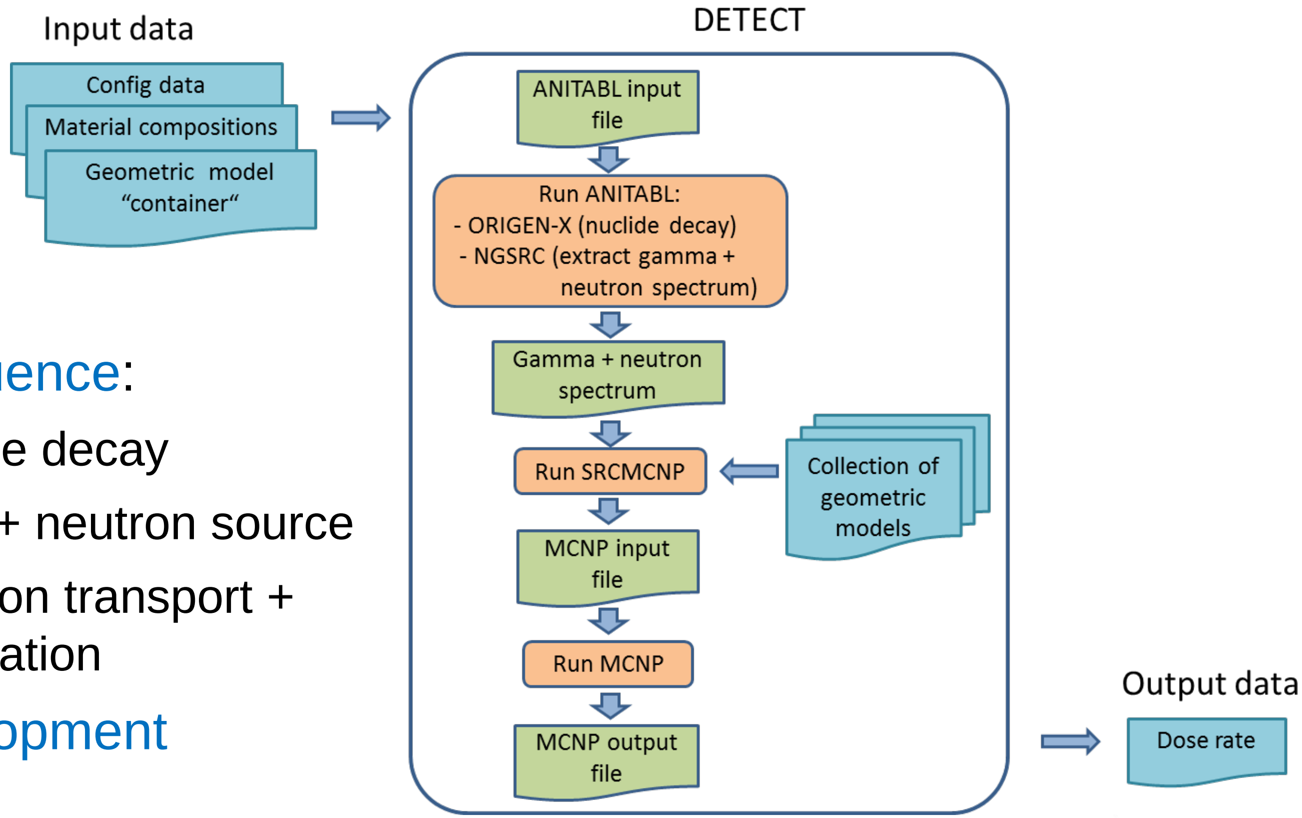
Activation calculation generic RPV (2)

- Calculating complete flux map is challenging
- Calculated activity (example):
  - ^{60}Co activity in the order of 10^8 Bq/kg_{Steal}



Current developments: DETECT (1)

- DETECT: Dose rate calculation tool
- Tool for (series) of 3D dose rate calculations



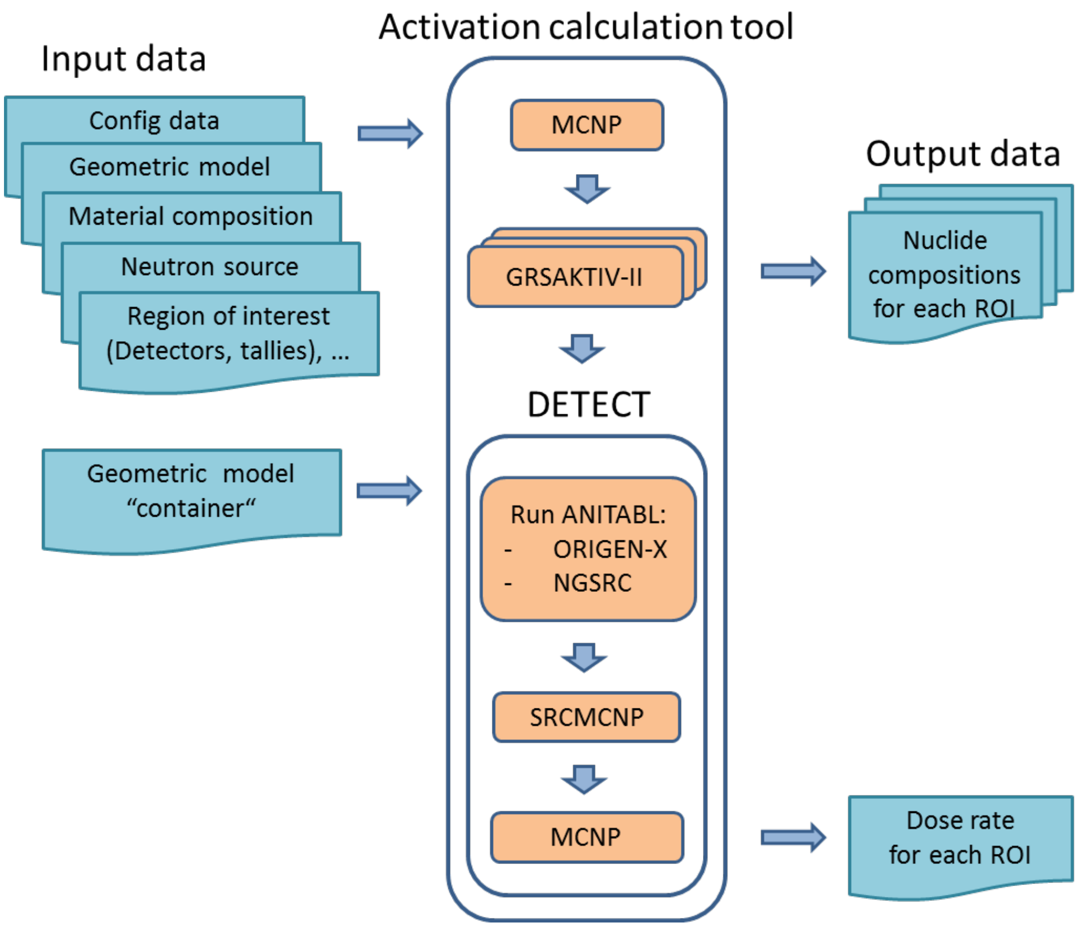
- Calculation sequence:
  - Calculate nuclide decay
  - Create gamma + neutron source
  - Gamma + neutron transport + dose rate calculation
- Still under development

Current developments: DETECT (2)

- Dose rate calculation using detailed 3D geometric models
  - „Container data base“: collection of predefined geometric models (e.g. waste containers)
- Automated gamma/neutron source definition based on user defined material (waste) composition
- Calculation sequence:
  - ANITABL → ORIGEN-X: Nuclide decay according to decay time (e.g. storage time)
  - ANITABL → NGSRC: create gamma + neutron source according to decay data
  - SRCMCNP: convert gamma + neutron source to MCNP input cards
  - MCNP: gamma + neutron transport calculation (dose rate tallies)

Current developments: activation + dose rate

- Next development step: Coupling of activation and dose rate calculations:



Conclusion

- Successful benchmark:
  - calculated neutron fluxes $\sim 10^{-10} - 10^{-4} \times$ source flux
  - Activation calculation of sample outside of RPV
- Generic RPV model:
  - Neutron flux and spectrum of large parts of RPV + segmentation (mesh tally) $\Rightarrow$ challenging
  - More elaborated methods needed to generate variance reduction parameters, e.g. ADVANTG
- Current code developments:
  - Activation calculations and dose rate calculations in 3D
  - Coupling activation and dose rate calculation