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Practical applications of ISOCS Multi-Efficiency modelling for complex pipe geometries at a nuclear power plant

– an in-house methodology development

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OKG Nuclear Power Plant: O1, O2 & O3

O3 is one of the world's biggest boiling water reactors (BWR), with a maximum power of 1450 MW. It is equipped to be in operation until year 2045, at least. During 2021, O3 produced 11 TWh of fossil free electricity, which is enough to supply around 1 000 000 Swedish households.

Decommissioning and dismantling of O1 and O2 gives us unique knowledge and develops skills and experiences.

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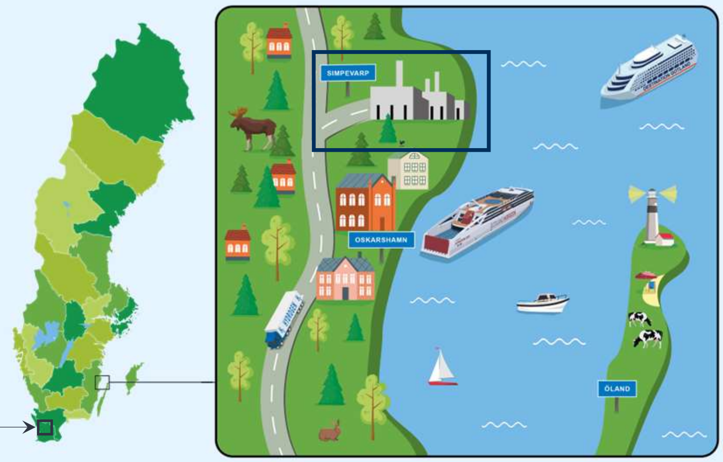
Our locations

OKG AB
Simpevarp
Oskarshamn



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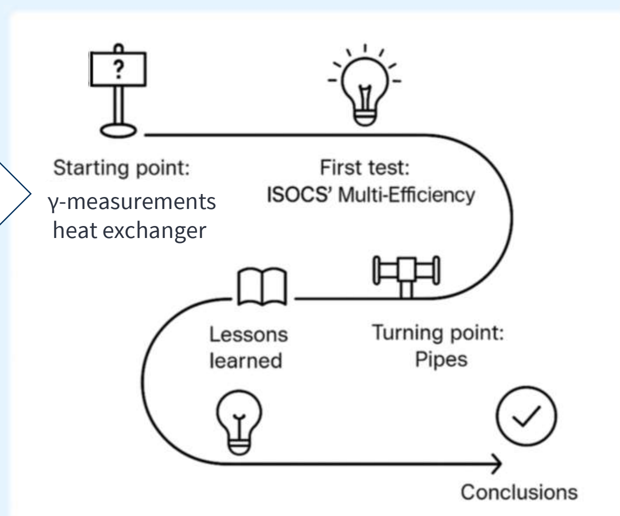
The story of this work



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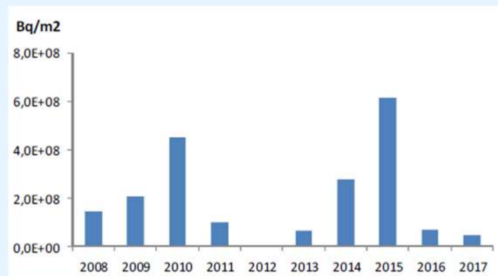
System Surface Activity γ-measurements

- Performed during yearly reactor outages
- Purpose: study trends of activated corrosion products on system surfaces [Bq/m^2]
  - Monitor plant radiological status
  - Support decisions on system decontamination campaigns
  - Bonus: Validate data models of activated corrosion product transport

Cr-51, Mn-54, Co-58, Co-60, Zr-95/Nb-95, Ag-110m, Sb-124, Sb-125

- 11 measurement-points, pipes and heat exchangers:
  - Main steam system
  - Residual heat removal system, reactor
  - Reactor water cleanup system
  - Hydraulic control rod insertion system, scram
  - Steam reheater (LP & HP turbines)



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Hardware and software

- Portable HPGe-detector Canberra Model: GR0519
- Liquid nitrogen-cooled
- Shielded: 10 cm lead
- Collimator: 12 mm
- Trolley with detector (~300 kg)
- Background measurements with completely closed collimator
- Genie2000 & ISOCS-Geometry Composer

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Measurement objects: Pipes and heat exchangers

1st case: Heat exchanger: Reheater in Turbine hall

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Measurement objects: Reheaters in turbine hall

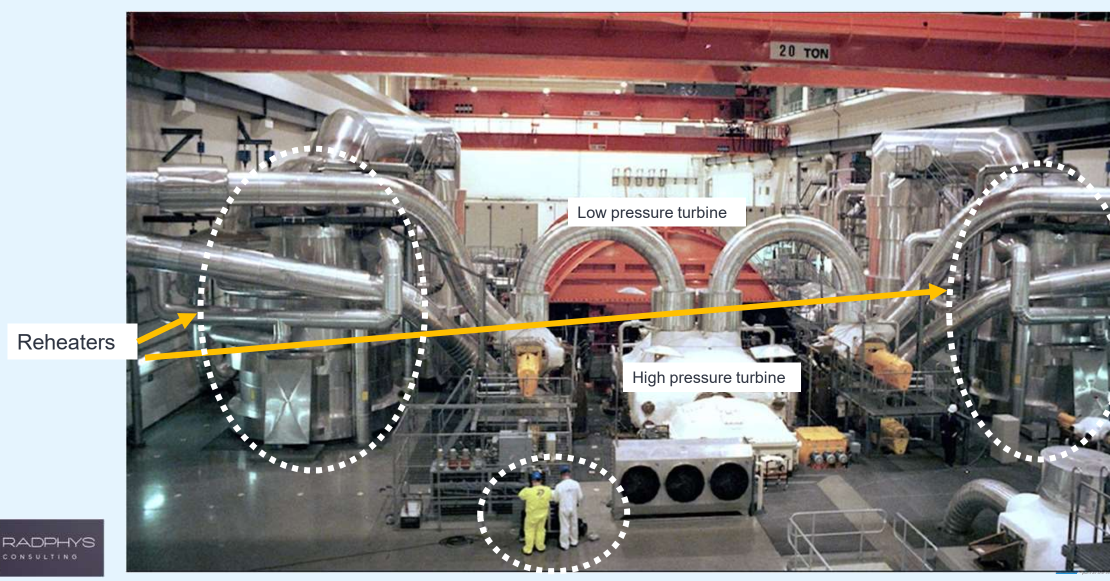

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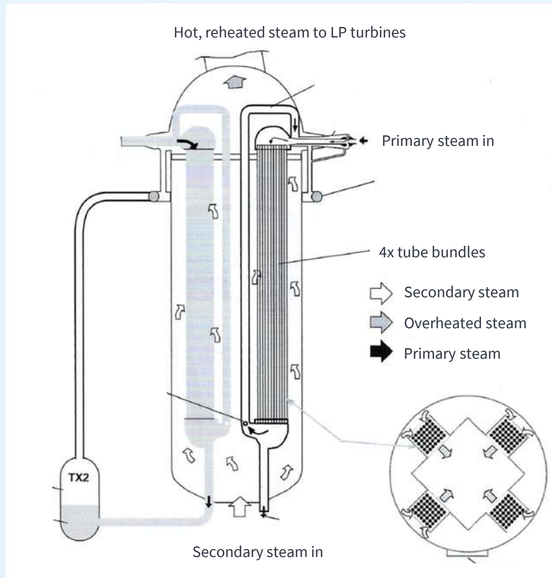
Illustration: Reheater in turbine hall

Dimensions for ISOCS-modelling:

- Vessel (Ø ~4 m)
- 4 tube bundles with steam inside & outside tubes
- Function: reheats turbine steam before LP turbines
- Deposition [Bq/m^2]:
    - Inside tubes
    - Tube outer surfaces
    - Vessel wall



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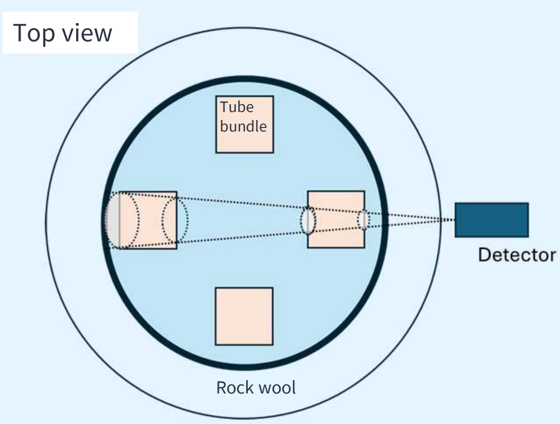
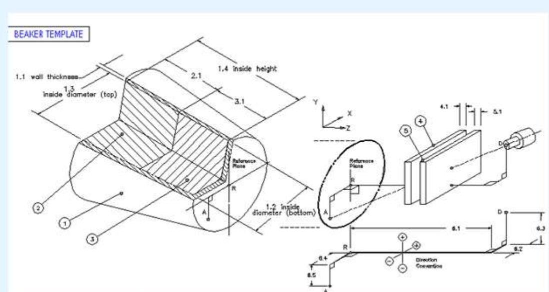
ISOCS' geometry for Reheater





Cone viewed from end – Beaker Template

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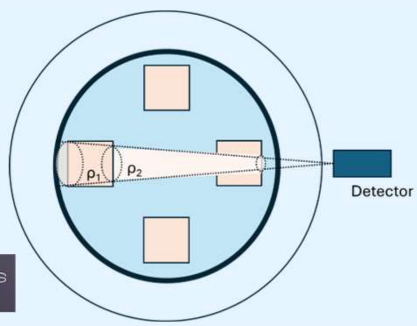
Solution: Averaging two simplified models

Model 1 – Beaker Template:

1. Back tube bundle modelled
2. Front part = homogeneous steel/air layer (volume-weighted density)

→ Underestimating the efficiency

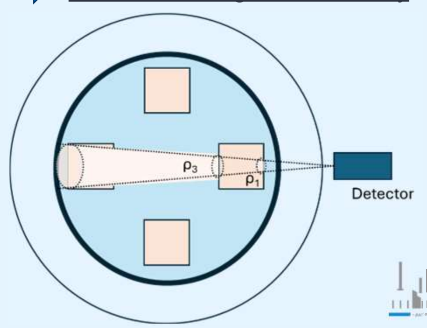
Rel. Act. Conc
0.90
0.10



Model 2 Beaker – Template:

1. Front tube bundle modelled
2. Back part = homogeneous steel/air layer (volume-weighted density)

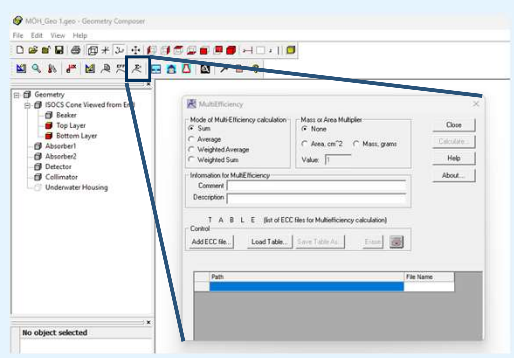
→ Overestimating the efficiency



Rel. Act. Conc
0.90
0.10

Updated methodology: ISOCS Multi-Efficiency

- Multi-Efficiency program in Geometry Composer allows creation of compound efficiencies
- Linear combination of efficiencies for partial geometries
- Each part defined by its activity contribution and its geometrical part of the total geometry
- Weighting coefficients depend on whether objects block each other fully, partially, or not at all.



$$\varepsilon_{total}(E) = x_1\varepsilon_1(E) + x_2\varepsilon_2(E) + \cdots + x_n\varepsilon_n(E)$$

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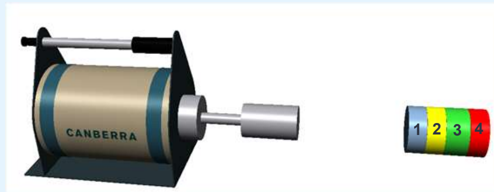
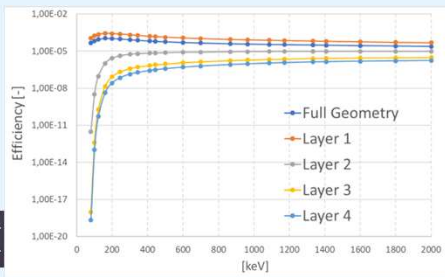
Test of ISOCS Multi-Efficiency function

- Test 4 active layers (steel, aluminum, water, steel)
- Prerequisite:
  1) Activity-concentration is known: 1:1:1:1
  2) Geometries fully blocking each other
- Individual efficiencies combined by linear regression
- **Result: weighting coefficient ≈ mass fraction**



$$\varepsilon_{total}(E) = x_1\varepsilon_1(E) + x_2\varepsilon_2(E) + \cdots + x_n\varepsilon_n(E)$$



	Relative Activity Concentration	Mass fraction	Weighting coefficient (num. Values)
Layer 1: Steel	1	40%	0.3996
Layer 2: Aluminium	1	6%	0.06445
Layer 3: H2O	1	14%	0.1361
Layer 4: Steel	1	40%	0.3995
	∑	100%	0.9997

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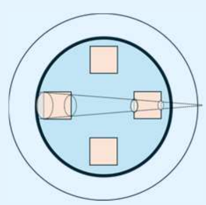
Updated methodology with ISOCS Multi-Efficiency

Partial geometry 1: Beaker Template
1. All activity in back tube bundle,
2. Front parts = passive absorbers, geometry preserved

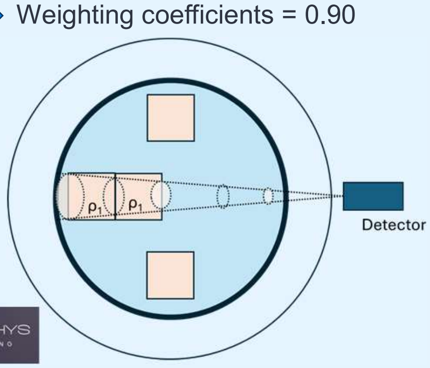


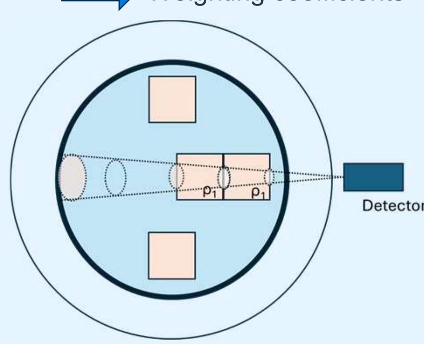
Partial geometry 2: Beaker Template
1. All activity in front tube bundle,
2. Back parts = passive absorbers, geometry preserved

➡ Weighting coefficients = 0.90

➡ Weighting coefficients = 0.10

Rel. Act.
Conc.
1.00
0.00





Rel.Act.
Conc.
0.00
1.00

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Comparison of methods

- Updated method (multi-efficiency) agrees well with earlier averaging method
- Deviations are small across all energies (< 3 %)
- Strengthens confidence in method and results

Energy [keV]	Efficiency Method 1	Efficiency Method 2	Difference
100	3,32E-13	3,38E-13	1,9 %
122	6,79E-12	6,95E-12	2,3 %
140	2,56E-11	2,61E-11	2,0 %
160	6,11E-11	6,23E-11	1,9 %
180	1,05E-10	1,07E-10	1,8 %
200	1,49E-10	1,51E-10	1,6 %
245	2,31E-10	2,35E-10	1,4 %
300	3,08E-10	3,07E-10	-0,2 %
344	3,49E-10	3,49E-10	-0,1 %
411	4,04E-10	4,05E-10	0,4 %
444	4,29E-10	4,30E-10	0,4 %
500	4,70E-10	4,72E-10	0,4 %
600	5,28E-10	5,41E-10	2,4 %
662	5,67E-10	5,84E-10	2,9 %
779	6,39E-10	6,57E-10	2,7 %
867	6,96E-10	7,14E-10	2,6 %
964	7,60E-10	7,79E-10	2,4 %
1086	8,46E-10	8,61E-10	1,7 %
1112	8,61E-10	8,79E-10	2,2 %
1173	9,04E-10	9,22E-10	2,0 %
1332	1,00E-09	1,02E-09	1,7 %
1600	1,13E-09	1,15E-09	1,0 %
2000	1,26E-09	1,27E-09	0,7 %

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Measurement objects: Pipes

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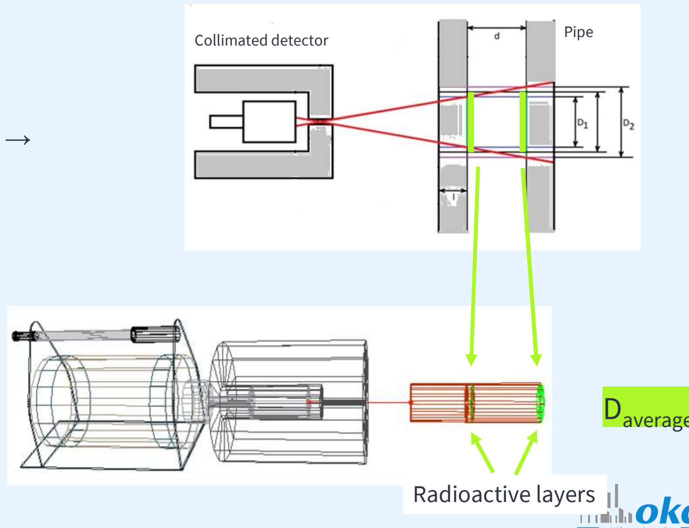
Earlier method: Pipes with averaged diameter

For ISOCS-modelling:

- Activity on inside surface
- Collimation & Background subtraction → coned view
- Small-angle approximation (< 5°)
- ISOCS template: *Circular plane*
- Active surface area → approximation: average diameter



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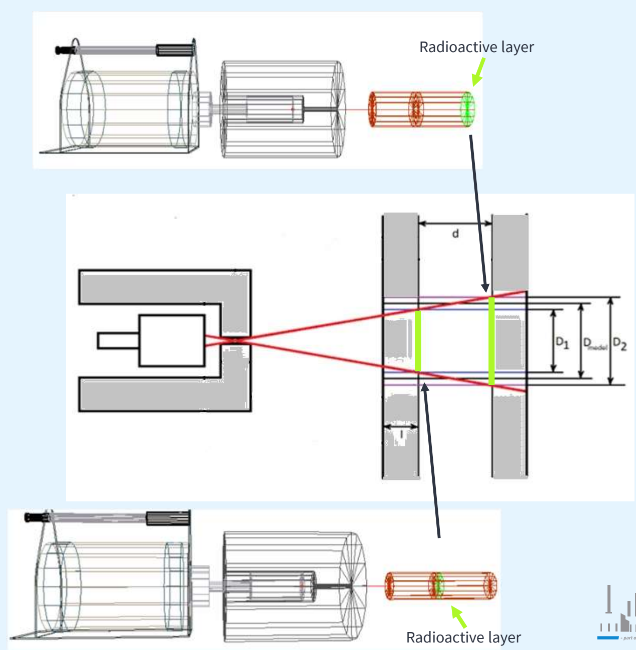
New method pipes: Multi-efficiency

- Active pipe areas → Split into sub-geometries
- Each with correct areas
- ISOCS template: *Circular plane*
- Linear combination with x_i = area fraction → total efficiency
- Homogenous activity distribution



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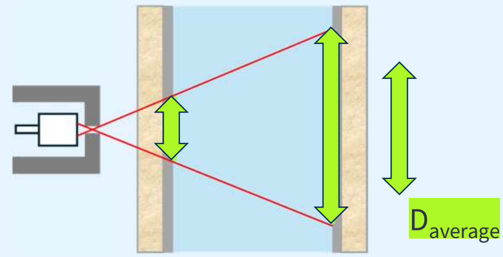
Comparison: Old vs New Method (Pipes)

- Air-filled smaller pipes → smaller differences
- Water-filled smaller pipes → larger differences

- Larger pipes → big differences
- → up to several 100 %



Pipe	Max. ΔEff –Air	Max. ΔEff –Water
Smaller pipes ~15 cm	3-5%	50-60%
Larger pipes ~ 60-80 cm	15-20%	200-400%

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Conclusions on methodology

- Earlier “averaging”-method → sometimes working, but not fully reliable
- Multi-Efficiency → geometries more accurate, works for both simple and complex geometries
- More precise models → reduced measurement uncertainties
- Take-home message: The Multi-Efficiency method allows us to build more complex geometries even when standard templates are missing

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Future work

- Background subtraction → energy dependent contribution from object background
- Evaluate measurement uncertainties (e.g., detector placement, geometries, background subtraction)
- Analyze ~200 measurements (2008–2025) with new geometries/calibrations
- A non-characterized detector was used < 2018
- Timeline: 31st October 2025

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