Studsvik

Assessment of Radioactivity Inventory – a key parameter in the clearance for recycling process

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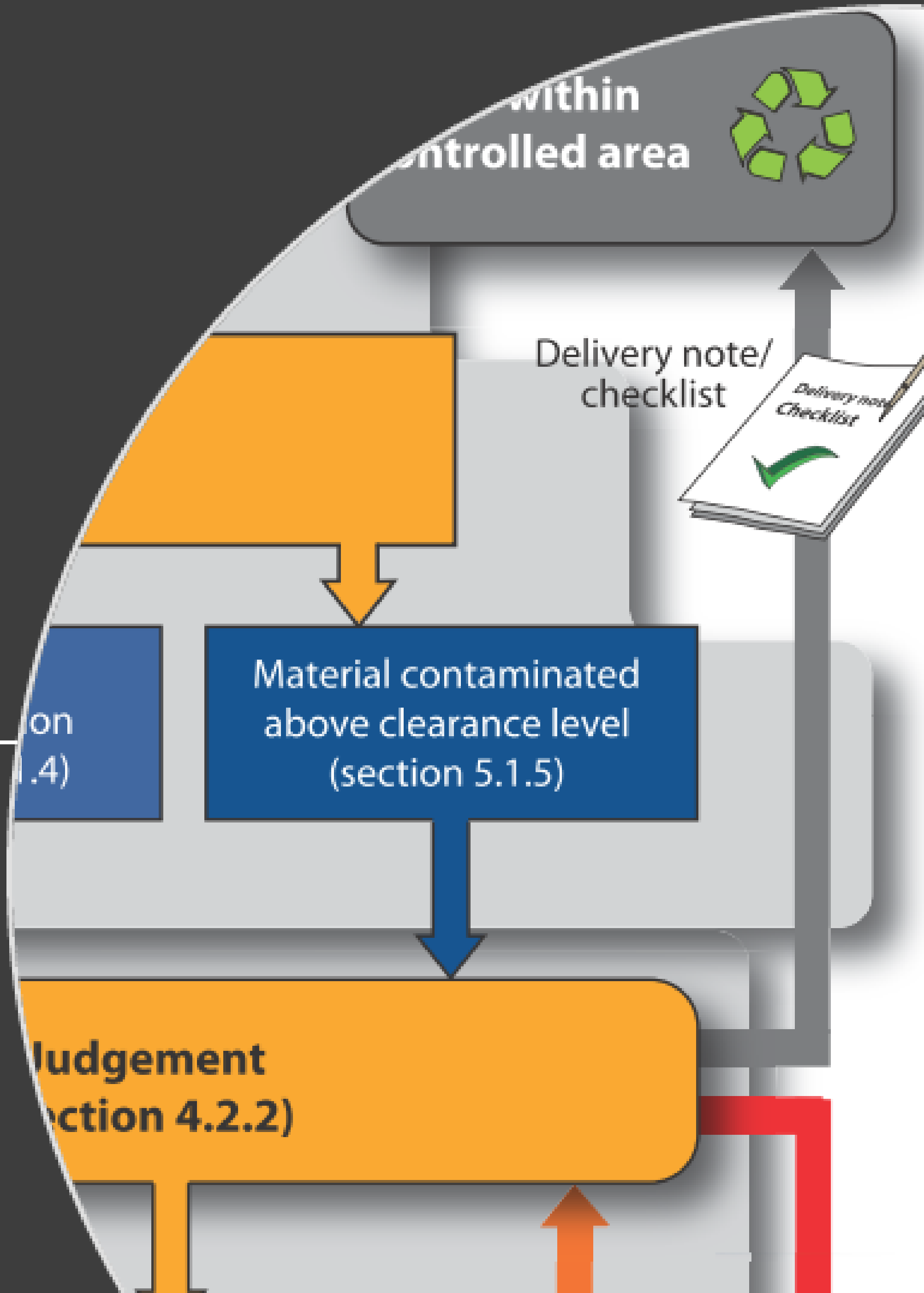
Background

- Studsvik was founded in 1947 as a state own research company with the mission to develop nuclear power in Sweden.
- Already in the old days Studsvik paid a lot of attention in materials characterisation. The interest in characterisation has remained with an increased focus on the back-end products.
- Studsvik has developed several models for theoretical and practical inventory determination.

Nuclide	$T_{½}$ [y]	λ [s^{-1}]	Daughter	Main source
H-3	12.3	1.79E-09		Fuel, Ind(B, Li)
Be-10	1.60E+06	1.37E-14		Fuel, Ind(Be, B)
C-14	5700	3.85E-12		Fuel, Ind(N)
Cl-36	3.01E+05	7.30E-14		Ind(Cl)
Ca-41	1.03E+05	2.13E-13		Ind(Ca)
Fe-55	2.73	8.05E-09		Ind(Fe)
Co-60	5.27	4.17E-09		Ind(Co)
Ni-59	7.60E+04	2.89E-13		Ind(Ni)
Ni-63	101	2.17E-10		Ind(Ni)
Se-79	1.10E+06	2.00E-14		Fuel, Ind(Se, Br)

Introduction

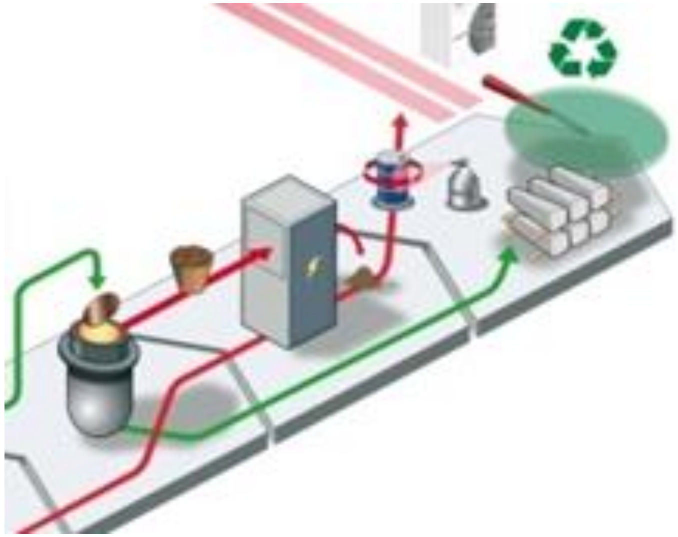


Why is assessment of the radioactivity inventory important?

- Key parameter in the decommissioning planning
- Required for demonstration of safety
- The basis for the development and licensing of disposal facilities
- Inventory data are required for the further handling of the material
- Good inventory understanding saves money and time

Overview - well developed areas

- Activity assessment for easy to measure nuclides (gamma)
- Assessment inside and close to NPP reactor pressure vessel
- Systems for which the models have been validated by measurements



Areas with development potentials

- Models for hard to measure nuclides
- Models for systems with low contamination levels far from the reactor core
- Nuclide distribution after treatment for critical nuclides (such as C-14 and Cl-36)
- Characterisation models for areas where nuclide vectors have varied by time.

Basics - Importance of good understanding

Process parameters:

- How the materials, systems and buildings have been contaminated – and decontaminated

- Variations in operations over the years and how it has effected the activity build up

Data quality objectives:

- Which nuclides are of importance, when and why?

Assessments performed – Reactors Permanently Shutdown

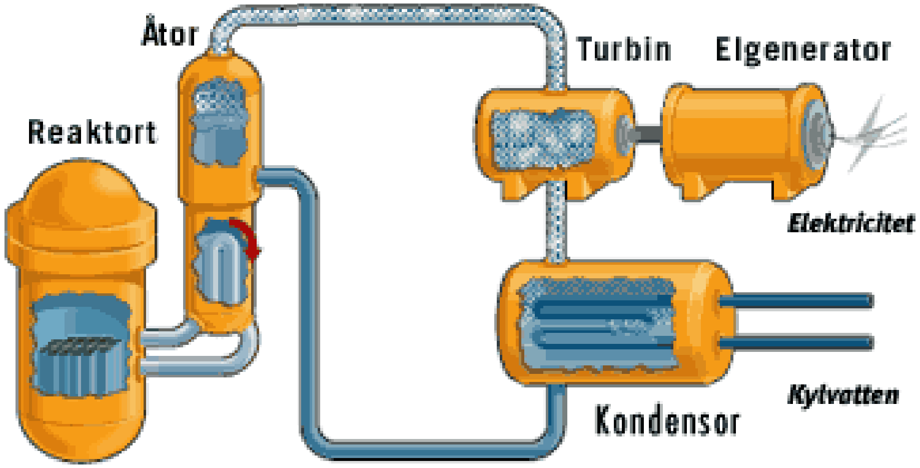
- **NPP Barsebäck-1 and -2 (BWR, closed 1999/2005):**
  - Project "RivAkt", Total activity assessment (2007)
  - evaluation of performed system decontaminations (2008),
  - improved assessment of activity in reactor internals (2013)

- **Ågesta (PHWR, closed in 1974):**
  - Total activity assessment (2010)

- **Studsvik-R2 (Research reactor, closed in 2005):**
  - Calculation of neutron induced activity

Assessments performed – Reactors in Operation

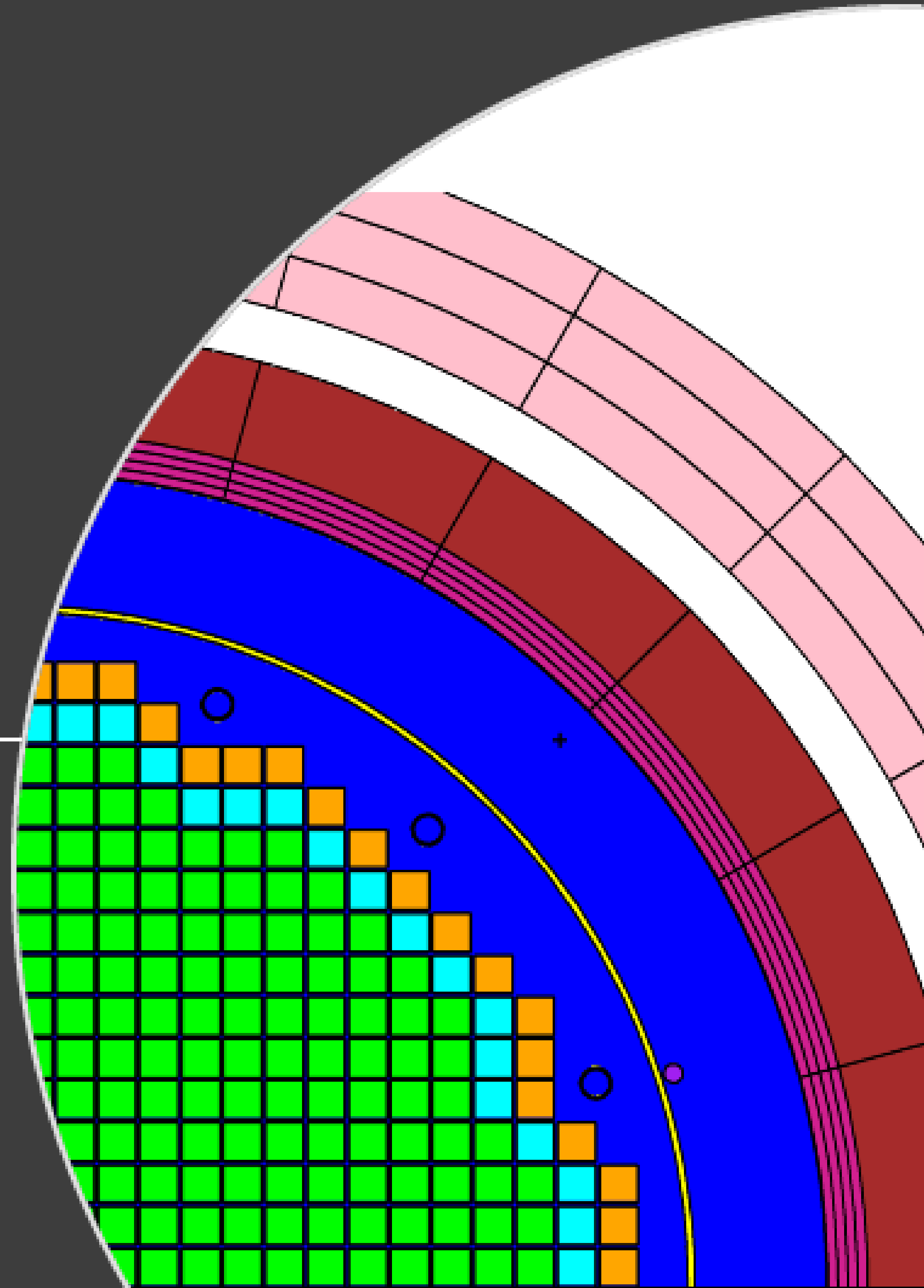
- **NPP Ringhals (1 x BWR + 3 x PWR):**
  - Total activity assessment (2007)
  - Update (2010, 2012)



- **NPP Forsmark (3 x BWR):**
  - Total activity assessment (2010)
  - Update (2012)

- **NPP Oskarshamn (3 x BWR):**
  - Total activity assessment (2010)
  - Update (2012)

Determination of activity inventories



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Prerequisites

- **Total operation time for each reactor is based on plant specifications**
  - Actual operation history for the Barsebäck, Ågesta and Studsvik reactors
  - Predicted operation times, 50 or 60 years, for reactors still in operation
- **Transition period (shorter) prior to dismantling**
  - Only nuclides with half-lives >1 years considered
- **Operational waste (spent fuel, resins, filters, etc.) excluded**
  - Some amounts of waste remain in the waste handling systems
- **No decontamination of primary loop prior to decommissioning**
  - Barsebäck plants where decontamination campaigns have been performed
- **Only plant materials with activity expected to exceed clearance levels are included**

Input to activity assessment

- **Safety Analysis Reports (SAR)**
- **Plant data**
  - Dose rate and gamma scan campaigns during outage
  - Reactor water activity data
  - Moisture content in steam (for BWRs)
  - Fuel leakage history data
- **Component data and surface areas in contact with active process media**
- **Known future operation conditions**
  - Remaining operation time
  - Planned modifications (e.g. power uprates), etc.

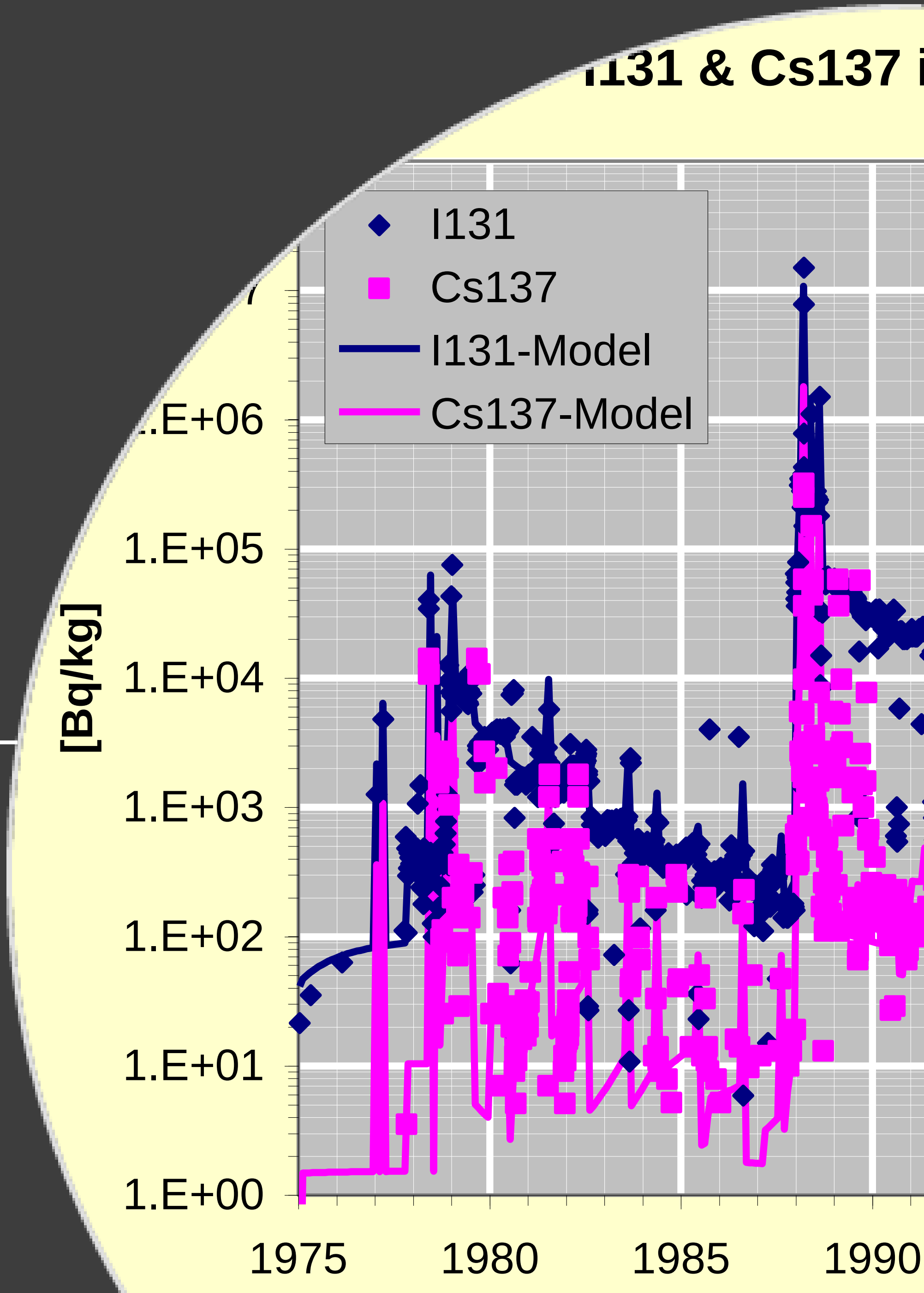
Source terms considered

- Neutron induced activity in internals, RPV and biological shield
- Activated corrosion products on system surfaces (“Crud”)
- Fission products and actinides from leaking fuel:
  - SAR leakage models combined with plant data
  - Fuel dissolution results in:
    - Actinide incorporation in system oxides
    - Tramp U on core → Noble gas daughters in turbine (BWR) and offgas systems
- Contamination of concrete from system leakage

Nuclides considered

- **Initially 28 nuclides**
  - H3, C14, Cl36, Ca41, Fe55, Ni59, Co60, Ni63, Sr90, Nb94, Tc99, Ag108m, Cd113m, Sb125, I129, Cs134, Cs135, Cs137, Sm151, Eu152, Eu154, Eu155, Pu238, Pu239, Pu240, Pu241, Am241, Cm244
- **Further 20 nuclides included in 2012 update**
  - Be10, Se79, Mo93, Zr93, Nb93m, Ru106, Pd107, Sn126, Ba133, Pm147, Ho166m, U232, U236, Np237, Pu242, Am242m, Am243, Cm243, Cm245, Cm246
- **Some additional nuclides being discussed, e.g.:**
  - Fe60 ($T_{1/2}$ = 1.5 My)
    - Fe58 (n, γ) Fe59 (n,γ) **Fe60** (β-) Co60m (IT) **Co60**
      Fe60 has high dose factors both for ingestion and inhalation
- ***Additional nuclides call for improved evaluation and validation processes***

Examples of performed validations



Example of validation:
Barsebäck – Activity removed from system decontaminations

ref.date	2007-11-01	2007-11-01	2007-11-01	2007-11-01
	B1/2008 [Bq]	B2/2007 [Bq]	B2/2002 [Bq]	TOTAL [Bq]
Co-60	1.33E+12	2.13E+12	7.55E+11	4.21E+12
Fe-55	6.72E+11	1.28E+12	6.69E+11	2.42E+12
Mn-54	8.01E+08	3.98E+10	7.91E+08	4.14E+10
Ni-59	1.68E+09	1.18E+09	1.63E+09	4.50E+09
Ni-63	2.13E+11	1.59E+11	2.13E+11	5.86E+11
Sb-125	2.30E+10	6.60E+10	2.44E+10	1.13E+11
Tc-99	8.44E+05	3.25E+05	4.48E+05	1.62E+06
Pu-238	3.41E+06	**4.69E+06**	**1.52E+07**	2.33E+07
Pu-239	4.13E+05	**5.44E+05**	**1.76E+06**	2.72E+06
Pu-240	6.75E+05	**8.89E+05**	**2.87E+06**	4.44E+06
Pu-241	1.07E+08	**1.83E+08**	**5.93E+08**	8.83E+08
Am-241	1.57E+06	**4.03E+05**	**1.30E+06**	3.28E+06
Cm-244	3.56E+06	**5.79E+06**	**1.87E+07**	2.81E+07

Memory effect of fuel dissolution in B2 in 1992 **(totally about 10 g U)**

Example of validation: Ringhals-3 Steam Generator

Findings:

- **Higher waste activity than determined by in-plant gamma scanning**
  - Complicated geometry to evaluate gamma scans (only peripheral tubes)
- **Ni63/Co60 ratio in line with earlier assessments**
- **C14 was detected in treatment residues**
  - The detected amount corresponds to about 0.24% produced in the coolant during one year
  - Additional evaluation discussed

Waste activity from processing in Studsvik				
	Bq, 1995-06-01			
Nuclide	Blasting	Melt	Other	Total
Co60	2.27E+12	2.20E+11	1.07E+12	3.56E+12
Ni63	2.23E+11	2.16E+10	1.05E+11	3.50E+11
Ni63/Co60				9.83E-02
C14	5.68E+08	5.51E+07	2.77E+08	9.00E+08
C14/Co60				2.53E-04

In-plant gamma scanning on SS and Inc				
	Bq, 1995-06-01			
Nuclide		Inc600	SS	Total
Co60		8.83E+11	9.20E+10	9.75E+11

Ni63 measurements performed by Studsvik
C14 measurements performed by Ringhals AB

Example of validation:

Barsebäck – Comparison between measured and calculated activity in RPV insulation and biological shield

	Caposil [Bq/kg]		**Aluminum Sheet** [Bq/kg]	
Nuclide	**Calculated**	**Measured**	**Calculated**	**Measured**
Co-60	3.3E+05	2.4E+05	8.4E+04	6.3E+04
Cs-134	1.4E+05	4.2E+04		
Mn-54	5.6E+05	5.2E+05	3.2E+04	2.0E-4
Zn-65			1-6E+05	6-3E+04
	Concrete [Bq/kg]		**Reinforcement** [Bq/kg]	
Nuclide	**Calculated**	**Measured**	**Calculated**	**Measured**
Co-60	7.6E+05	3.0E+05	2.7E+07	6.2E+06
Mn-54			1.3E+07	5.3E+06
Cs-134	9.0E+04	5.5E+04		
Eu-152	1.8E+06	1.3E+06		
Eu-154	1.6E+05	1.2E+05		

Conclusions

- Existing inventory assessment models are considered to be of good international standard
- Validations of models by measurements have been performed in “easy” areas - good result
- Critical nuclides in a clearance and disposal perspective are different
- Further efforts may be needed/of advantage
  - to reduce uncertainty – especially far from the reactor core
  - to validate the inventory assessment models

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