# PBMR:
# Product Overview & Source Term Modelling

**PSI HTR Dust Issues Meeting**
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**Paul Scherrer Institut, Villigen, Switzerland**

# PBMR:
# Product Overview & Source Term Modeling

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# PBMR PRODUCT OVERVIEW

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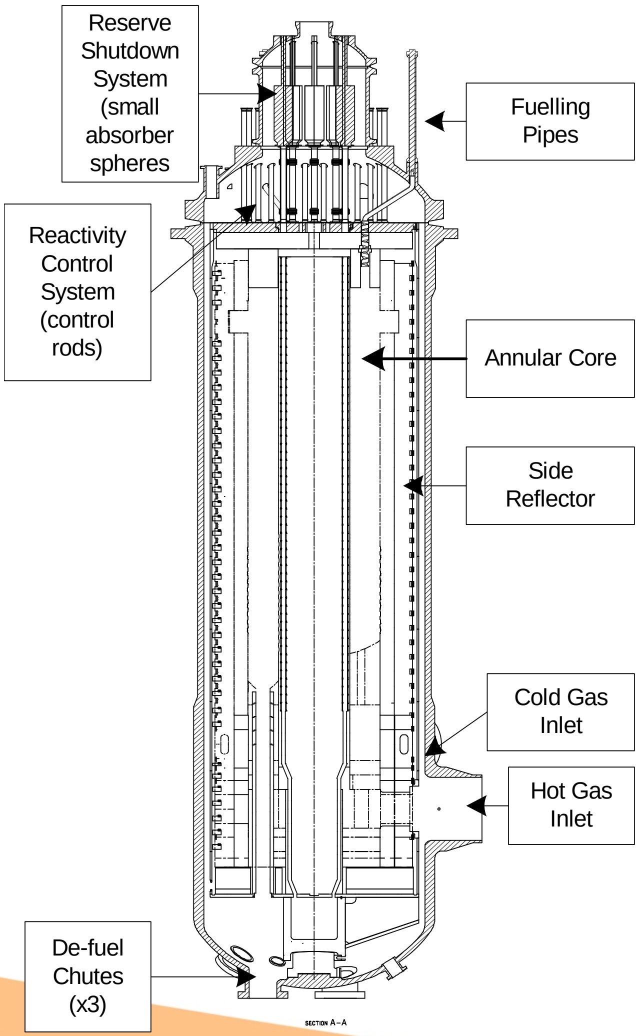
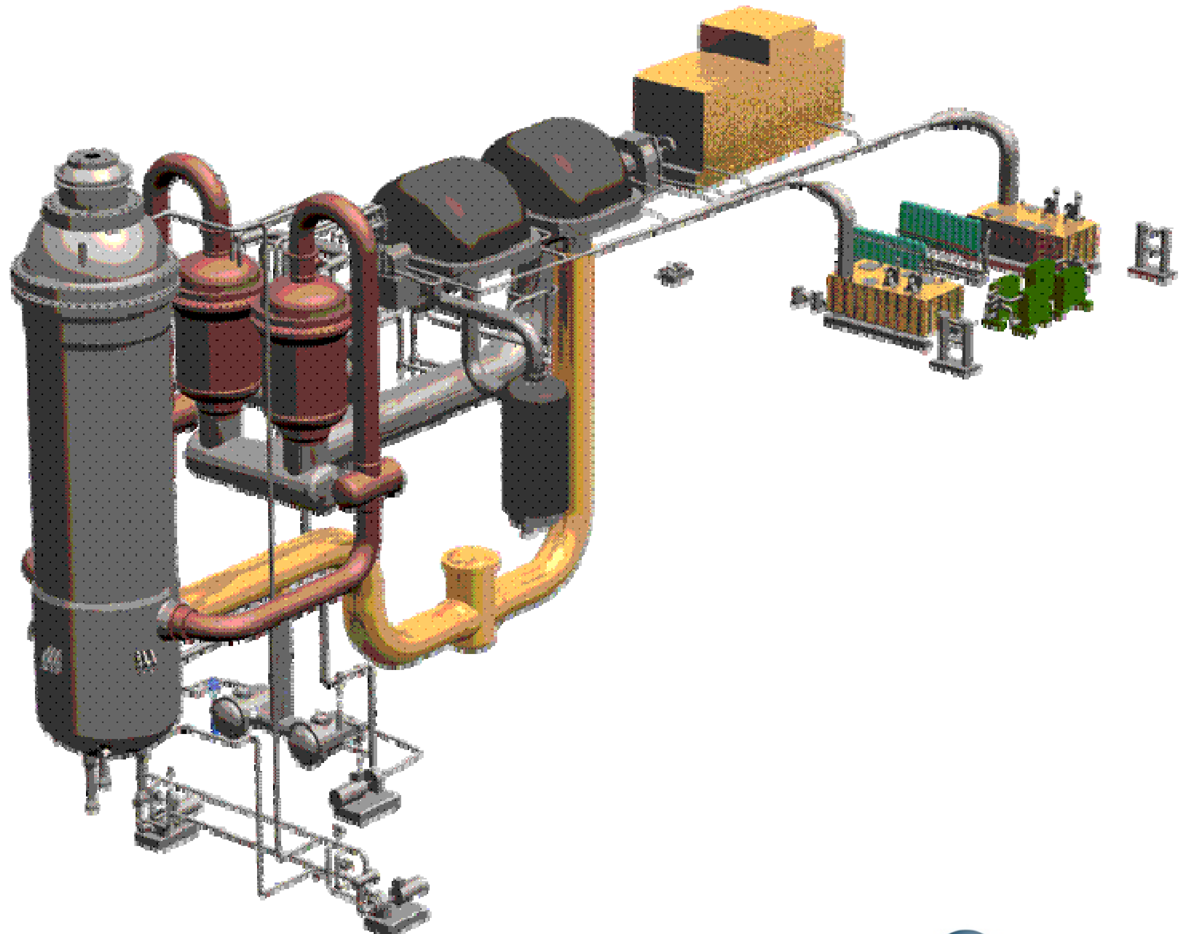
# 400 MWt Reactor Unit
# Electricity Generation



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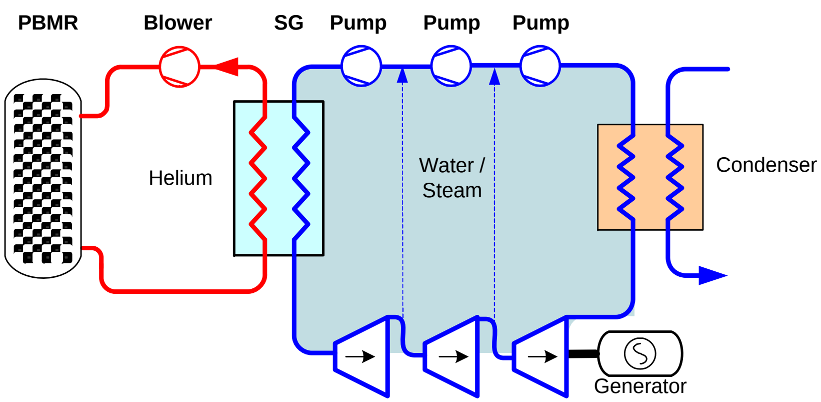
# Product change from PBMR 400MWt to 200MWt

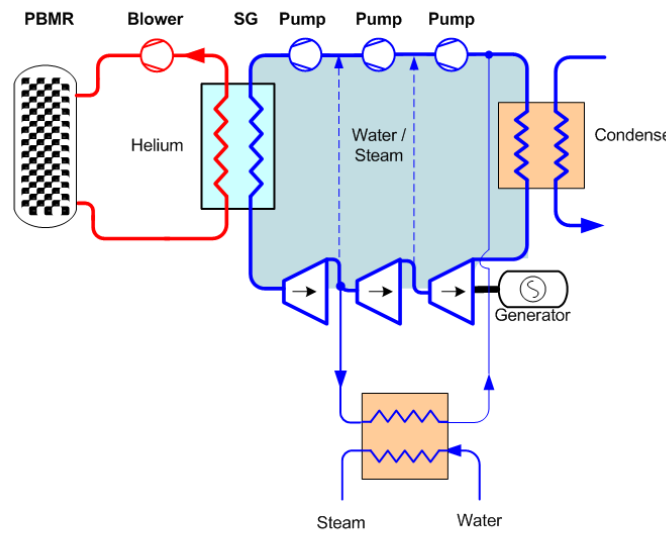
- The global financial crisis
  - Affected funding of some South African State-owned Enterprises
    - Eskom - Nuclear I (PWR program) delayed.
- Near-term Market Opportunities
  - Based on prospective customer requirements – There is an opportunity to service both the electricity and process heat markets.
  - Decision made to develop a standard nuclear heat supply source capable of servicing both markets.
- Modification of the design to service prospects such as:
  - The Next Generation Nuclear Plant (NGNP) project in the US
  - Oil sands producers in Canada (to extract bitumen from oil sands),
  - The petro-chemical industry and large process steam users
- Modular design of ~200MWt (simplified design to reduce risks)
  - Modular concept with the potential to link more than one reactor to a single power turbine or to supply process steam
  - Increase availability with multi-pack – no interruptions of steam supplied to the client

# PBMR Products

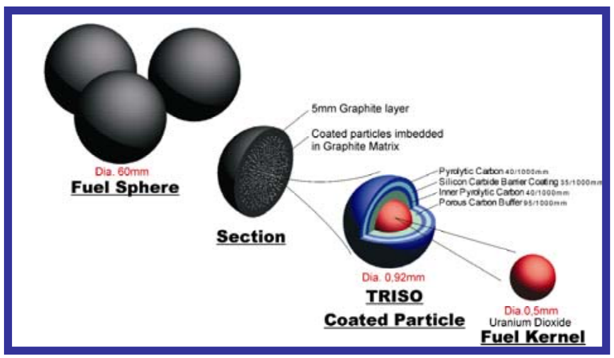



**Electricity**

**Process Heat**




**Co-generation**




**Fuel**

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# Where is PBMR now?

- Employees ~ 900 (Centurion & Pelindaba)
- New 200 MWt DPP Rankine Cycle selected (to demonstrate co-generation)
- Design & licensing work underway
- Eskom – host & operator at Koeberg
- Consortium of customers being pursued (petro-chemistry industry and large energy users)
- Fuel testing & qualification in Fuel Development Labs at Pelindaba
- Supply chain – localization focus
- Test facilities at Pelindaba & North-West University
- US DOE NGNP participation

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# Source Term Analysis & Dust Modelling

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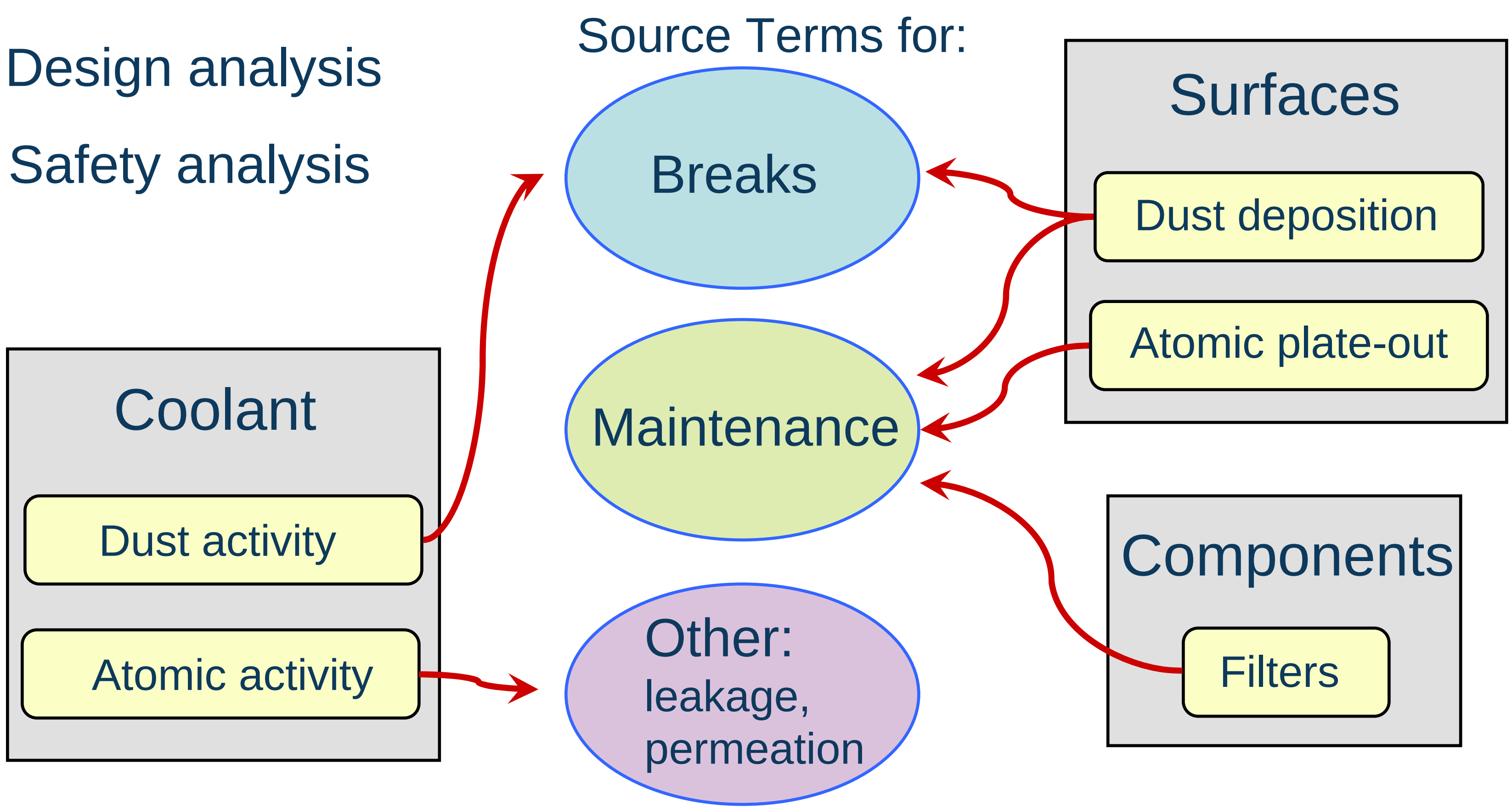
# Helium Pressure Boundary (HPB) Source Term Calculations

- Design analysis
- Safety analysis

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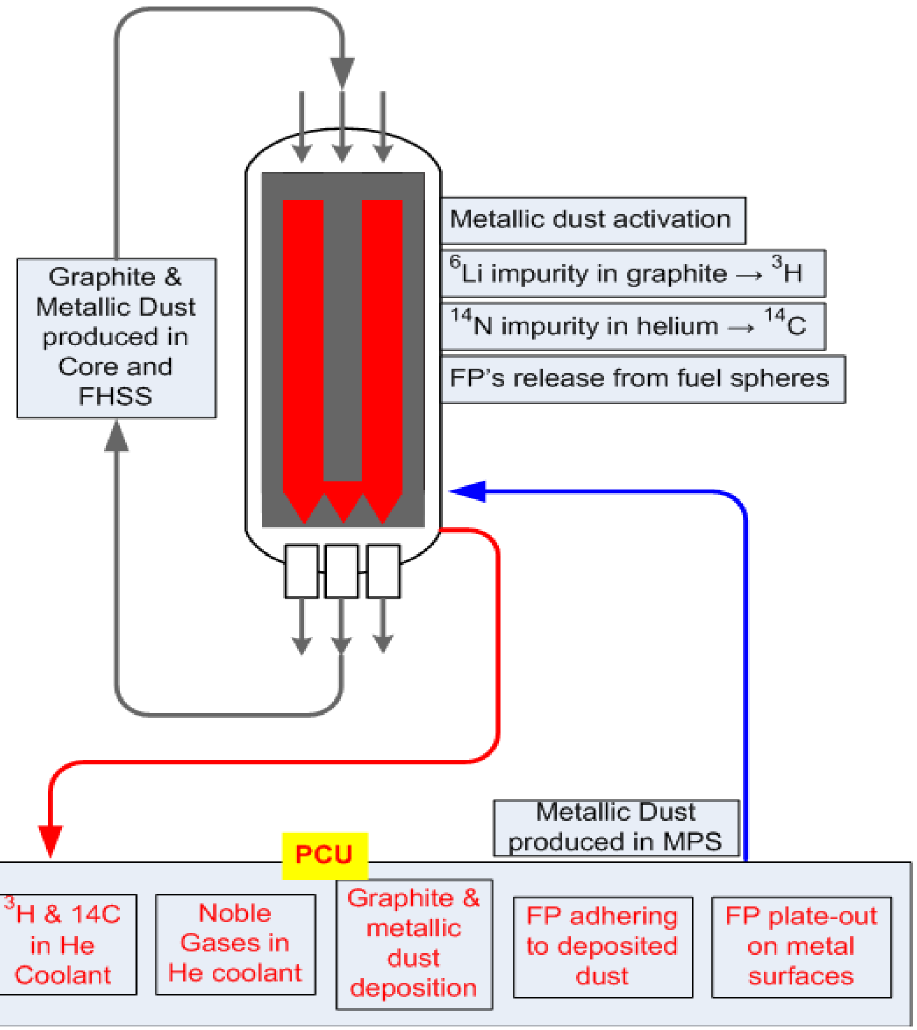
# HPB Source Term Drivers

- **Fuel Radionuclide release rates**
  - Fuel inventory
  - Graphite impurities
  - Quality of kernel coatings
  - Fuel temperatures

- **Activation of circulating nuclides in coolant and with dust**
  - Atomic migration phenomena
  - Graphite and Metal dust production
  - Dust migration phenomena:
    - In coolant
    - With fuel spheres

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# PBMR HPB Source Term Modelling History (1)

- SPATRA (FZJ): Initial plate-out evaluations (~2000)
  - limitations
    - no precursor sources modelled
    - no dust modelling
- RADAX (HRB): Fission Product (FP) and dust distribution and transport (up to 2007/8)
  - limitations
    - limited dust modeling (deposition, resuspension, migration)
    - no FP/dust interaction - manual post-processing
    - unrealistic distribution (no dust retained in core, Spent Fuel Tank)
  - uncertainties in model parameters
  - assumptions difficult to justify without experimental work

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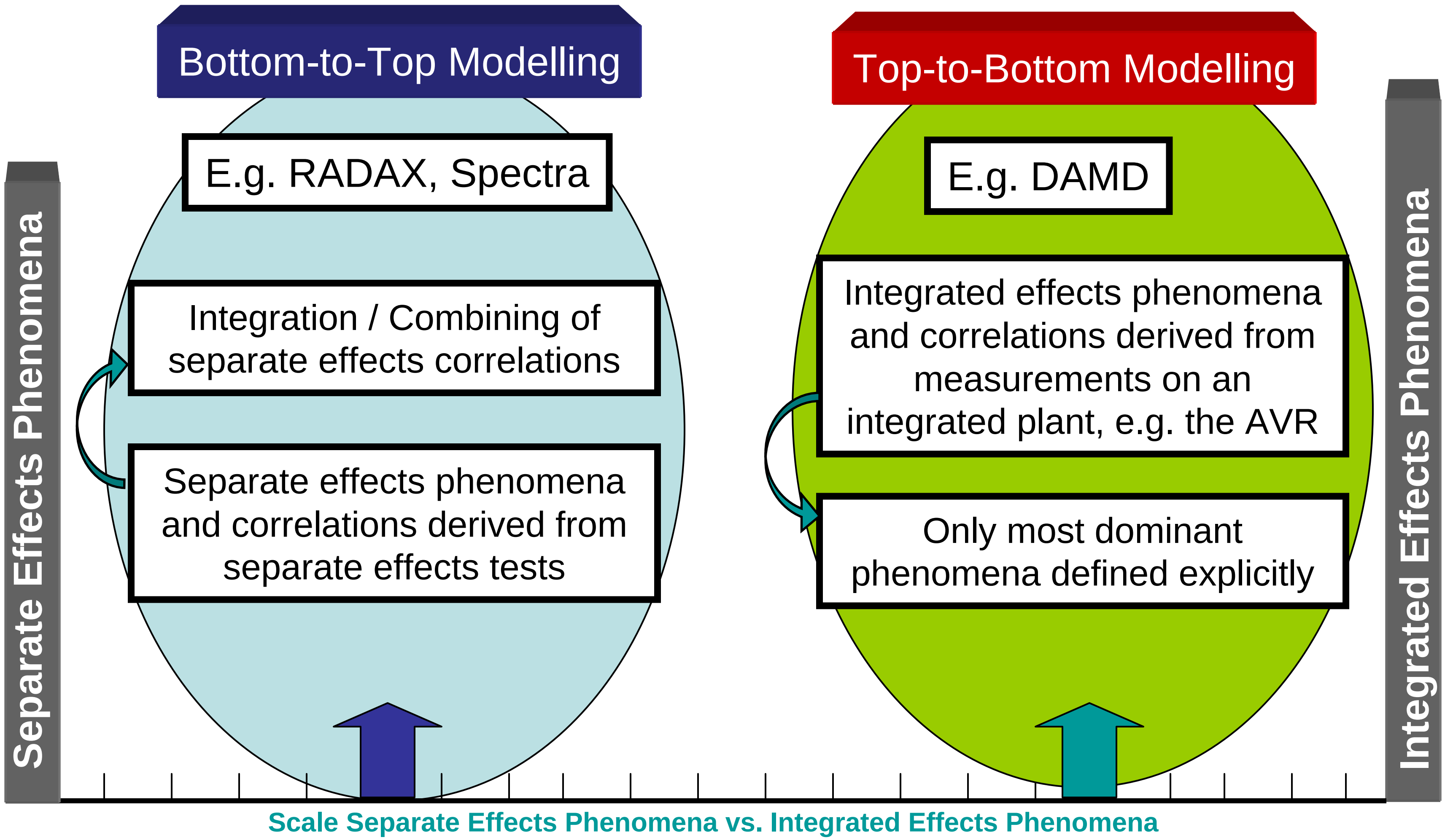
# PBMR HPB Source Term Modeling History (2)

- Conclusions from Oct 2008 evaluations:
  - metallic dust migration and activation models insufficient
  - justification for assumed sorption of FP on dust insufficient
- Recommendation: base Source Term analyses on existing reactor operating experience
  - improved analysis code required
- SPECTRA
  - NRG-developed thermal-hydraulic code with FP Transport package
  - fully integrated system analysis code for various reactor types
- RADAX/SPECTRA approach requires specific validation data
  - challenge to obtain suitable data for all models/phenomena
- Alternative modeling approach adopted – Dust & Activity Migration & Distribution (DAMD) development

# Radionuclide Transport Modelling Approaches




**Reasonable modelling of a full HTR plant depends on:**

- **Suitability of the separate effects test conditions**
- **Correct implementation of integration cross-terms**
- **Inclusion of changing separate effects input data** (e.g. surface roughness that changes over operating life)

**Reasonable modelling of a full HTR plant depends on:**

- **Using the AVR to calibrate the migration parameters**
- **Scalability of the dominant phenomena in the AVR to the HTR plant**

# DAMD Modelling Approach

Dust and Atomic particle Migration Model

DAMD

## Deposition Rates

Explicit modelling of Forces

- Hydraulic force (flow conditions)
- Gravity force

Lumped (non-explicit) modelling of Forces (e.g. thermophoresis, van der Waals Forces)

- Calibrated correlation

Calibrated against AVR

## Lift off Rates

Explicit modelling of Forces

- Hydraulic force (flow conditions)
- Transient forces
- Centrifugal force

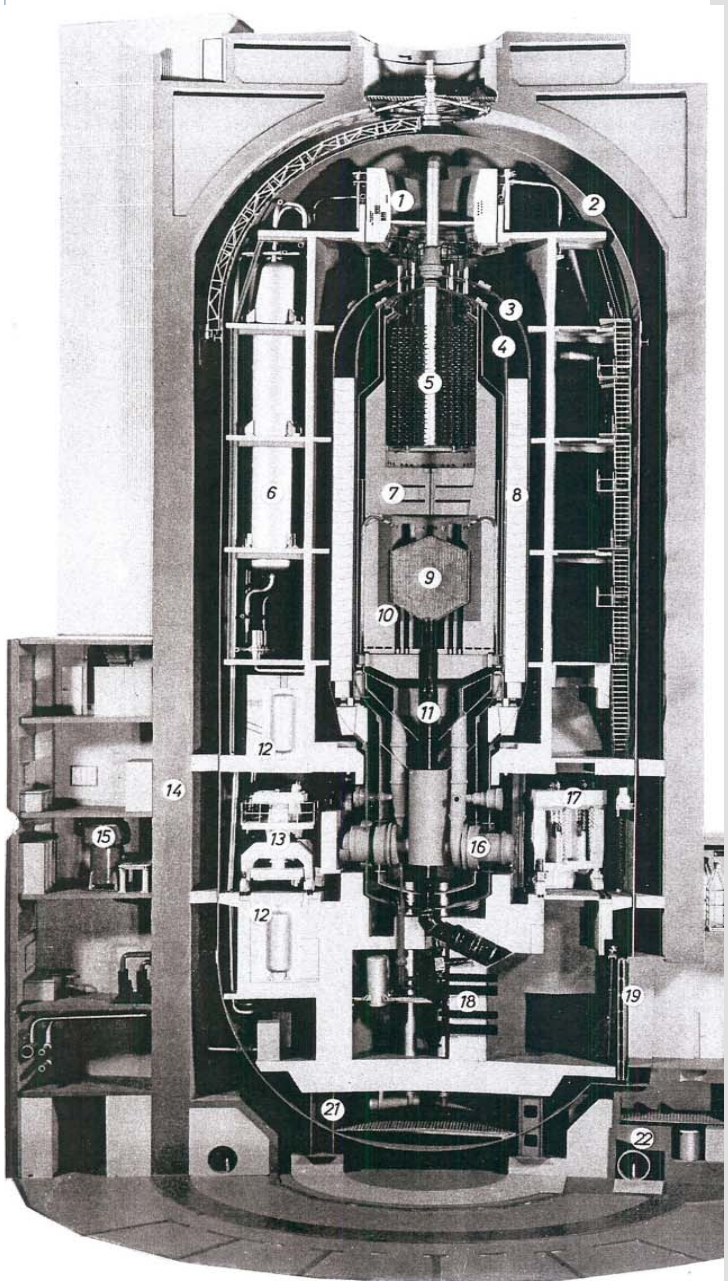
Lumped (non-explicit) modelling of Forces (e.g. vibrations, van der Waals Forces)

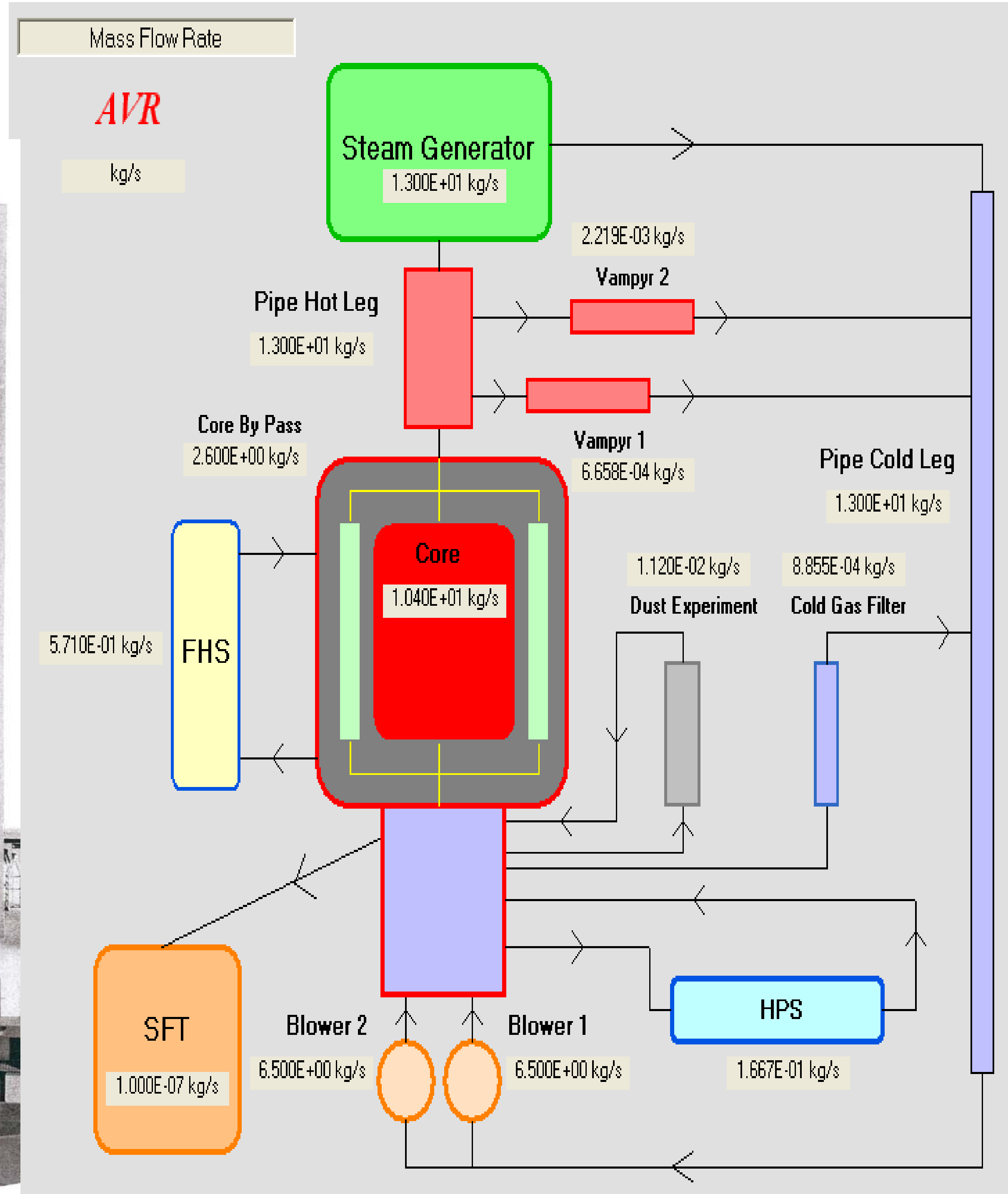
- Calibrated correlation

# DAMD Results for AVR and PBMR

**Note: Only a few results are shown. Many more results and experiments are available**

# DAMD AVR Model



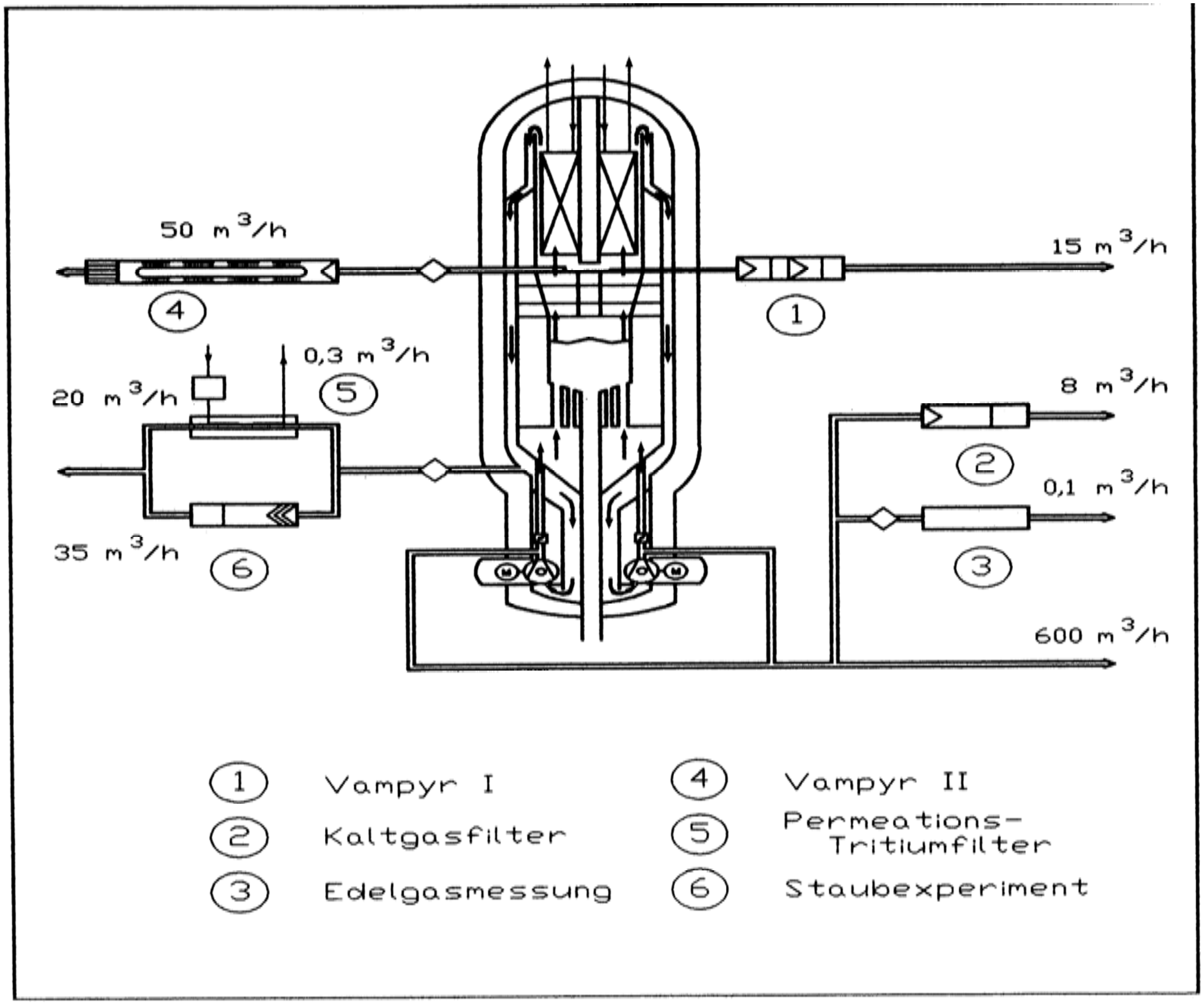


# Experimental Loops on the AVR

- Vampyr I: 49 exp.'s, '72 –'89
- Vampyr II: 4 exp.'s, '87 – '88
- Cold Gas Filter: 52 exp.'s, '72 –'89
- Dust experiment: S1-S15 (both lines), '84 – '87;

  SA1-SA5 (Line 2), '87–'88
- Dust remobilization exp.'s T1 –T5: measured in cold gas filter, Vampyr I & Dust Exp.,

  '86 – '88

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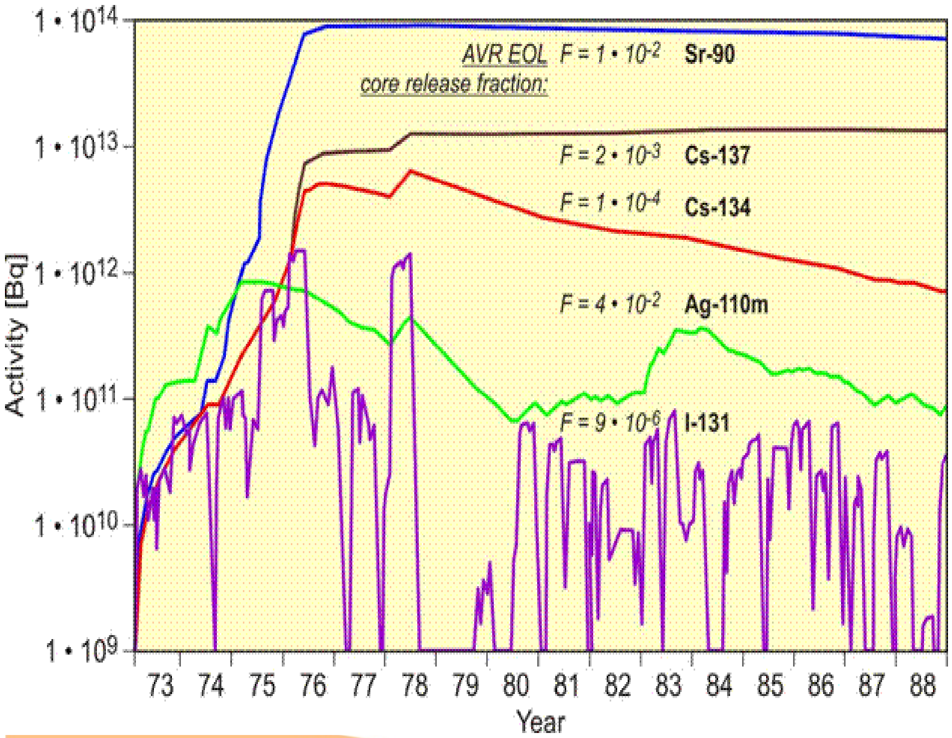
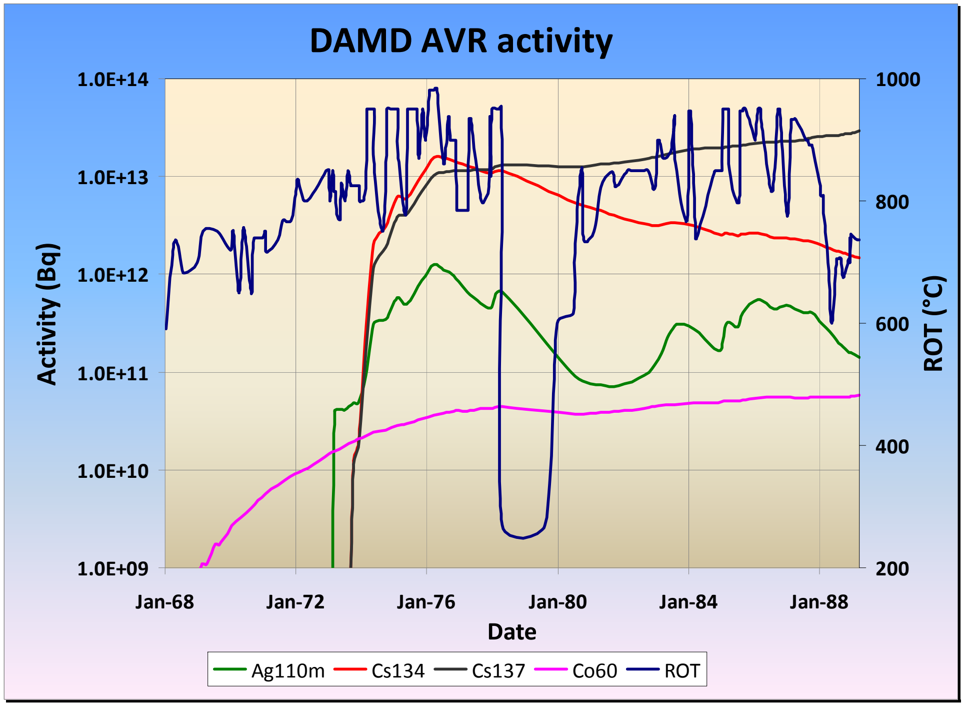
# AVR Activity Results with DAMD 3-Flow Channel Model

- Fuel Temp's for 20% core by-pass flow
- Fuel performance based on Fuel Release Factors for AVR fuel history




**3 Flow Channel**
**(15% Hot, 70% Average, 15% Cold)**

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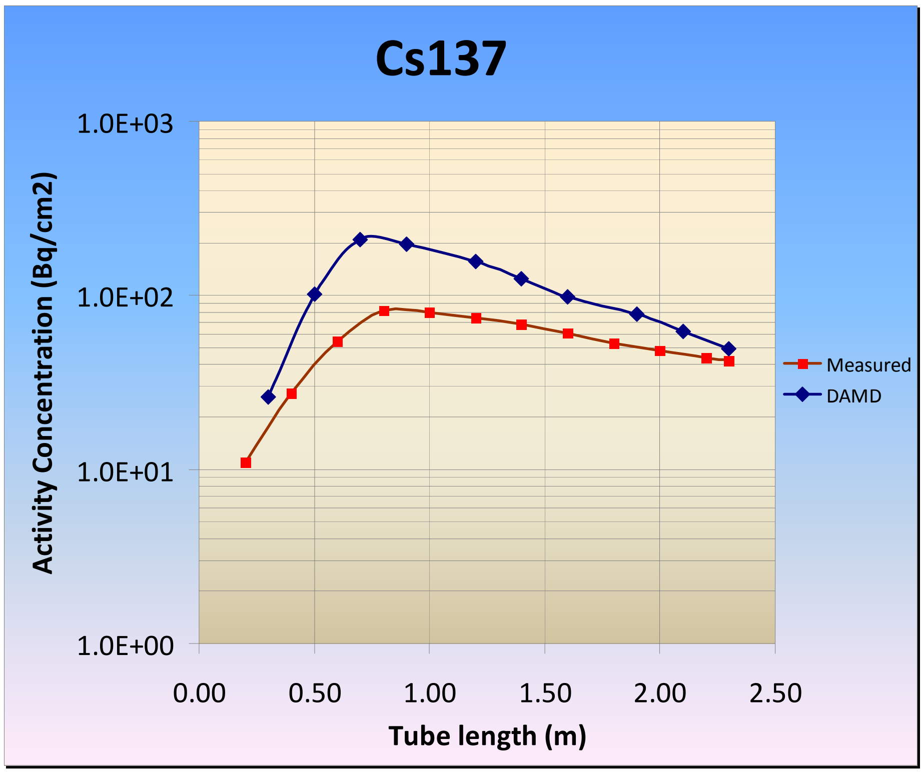
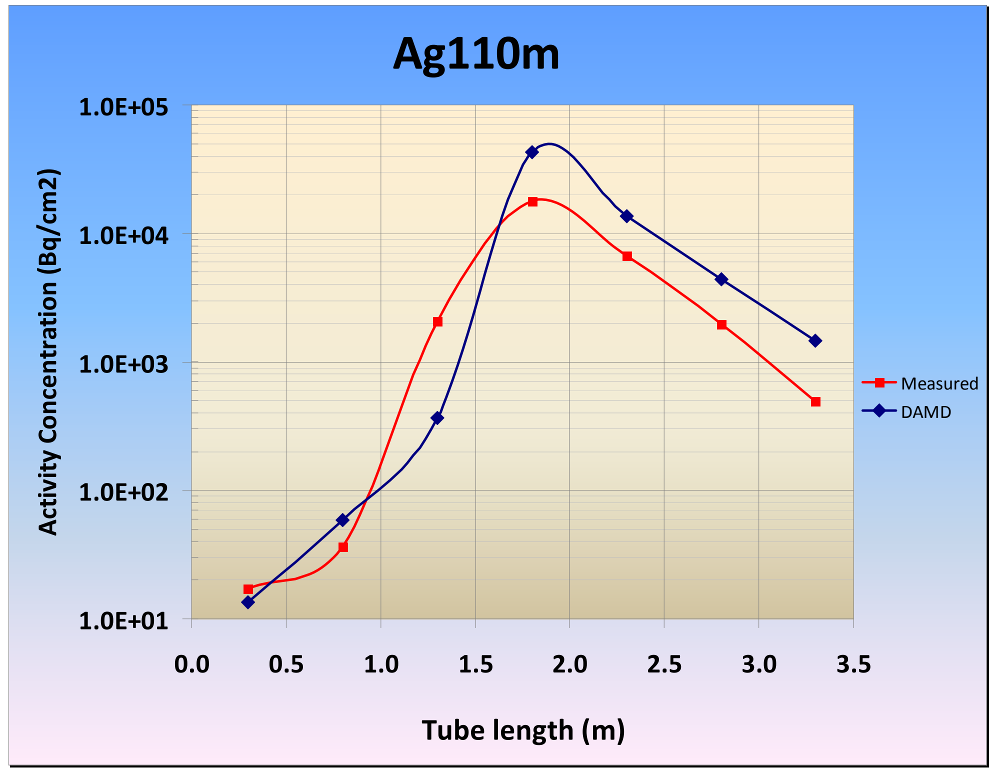
# DAMD AVR Comparisons: Dust & Activity Values

| Location / Experiment | Year | Parameter | Unit | Nuclide | AVR Measured | DAMD | DAMD / Measured |
|---|---|---|---|---|---|---|---|
| All Experimental Loops | Life-time | Circulating Dust Concentration | µg/m$^3$ | - | 7.80 | 8.00 | 1.0 |
| VAMPYR II Test 3 & 4 | 1988 | Circulating Metal Dust Content | % | - | 27 | 19 | 1.4↓ |
| VAMPYR I | Life-time | Dust Activity | Bq /g | $^{60}$Co | 2.5x10$^6$ | 2.4x10$^6$ | 1.0 |
| | | | | $^{110m}$Ag | 4.3x10$^6$ | 6.1x10$^6$ | 1.4↑ |
| | | | | $^{137}$Cs | 2.0x10$^7$ | 1.2x10$^8$ | 5.9↑ |
| Cold Gas Filter | Life-time | Dust Activity | Bq /g | $^{60}$Co | 8.9x10$^5$ | 1.2x10$^6$ | 1.4↑ |
| | | | | $^{110m}$Ag | 2.7x10$^6$ | 8.7x10$^6$ | 3.2↑ |
| | | | | $^{137}$Cs | 1.7x10$^7$ | 5.3x10$^7$ | 3.2↑ |
| Blower Maintenance | 1978 | Surface Activity | Bq/m$^2$ | $^{60}$Co | 2.4x10$^7$ | 1.6x10$^8$ | 6.4↑ |
| | | | | $^{110m}$Ag | 1.8x10$^8$ | 2.6x10$^8$ | 1.5↑ |
| | | | | $^{137}$Cs | 2.8x10$^9$ | 1.4x10$^{10}$ | 5.0↑ |
| DEACO I | 2007 | Surface Activity | Bq/m$^2$ | $^{60}$Co | 3.4x10$^5$ | 9.3x10$^4$ | 3.7↓ |
| | | | | $^{137}$Cs | 5.9x10$^7$ | 4.3x10$^8$ | 7.3↑ |

# DAMD AVR VAMPYR Plate-Out Comparisons




Comparison between VAMPYR I V09 test and DAMD for Cs137 Plate-out on 15Mo3 tube




Comparison between VAMPYR II V01 test and DAMD for Ag110m Plate-out on Incoloy 800 tube

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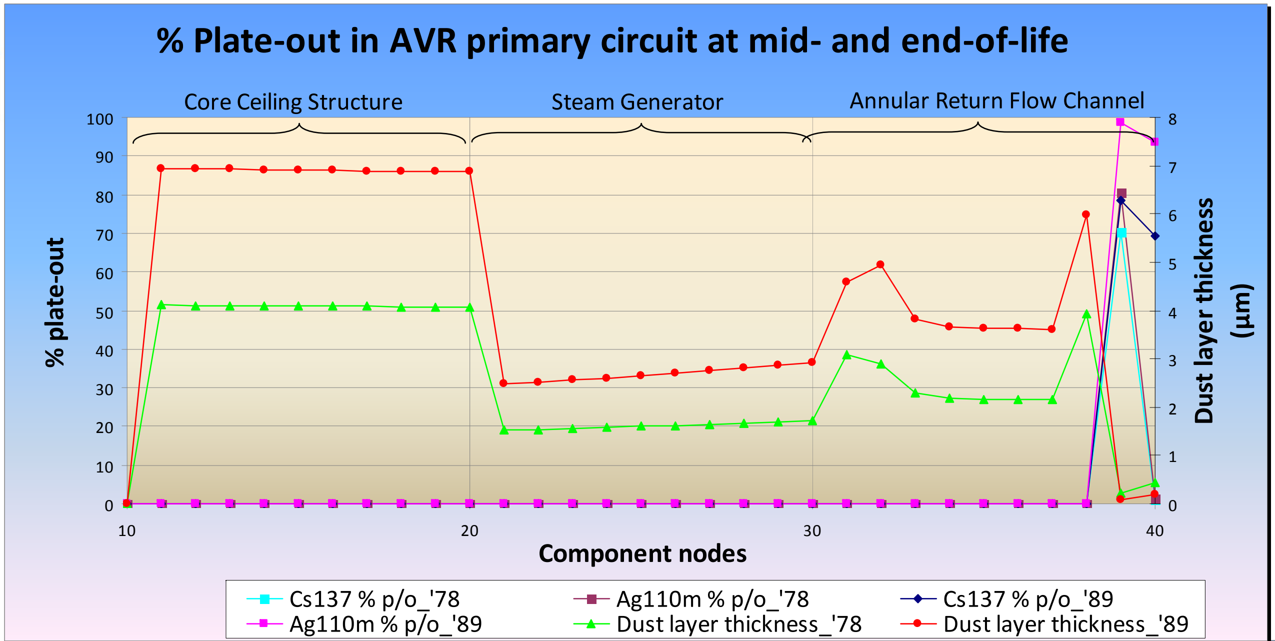
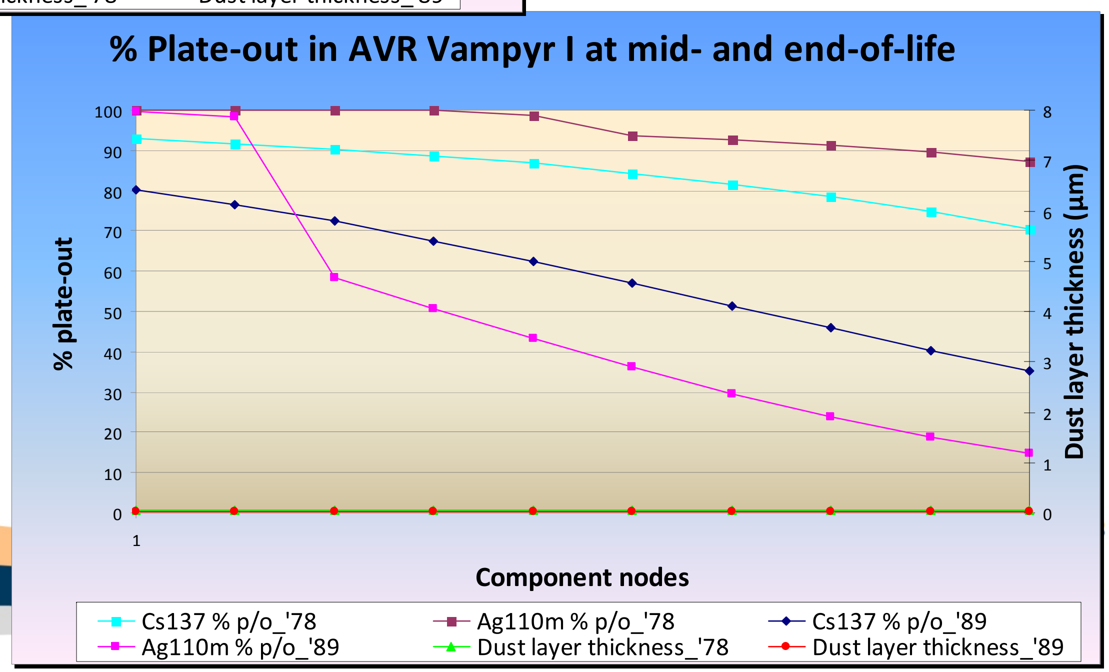
# DAMD AVR % Plate-Out

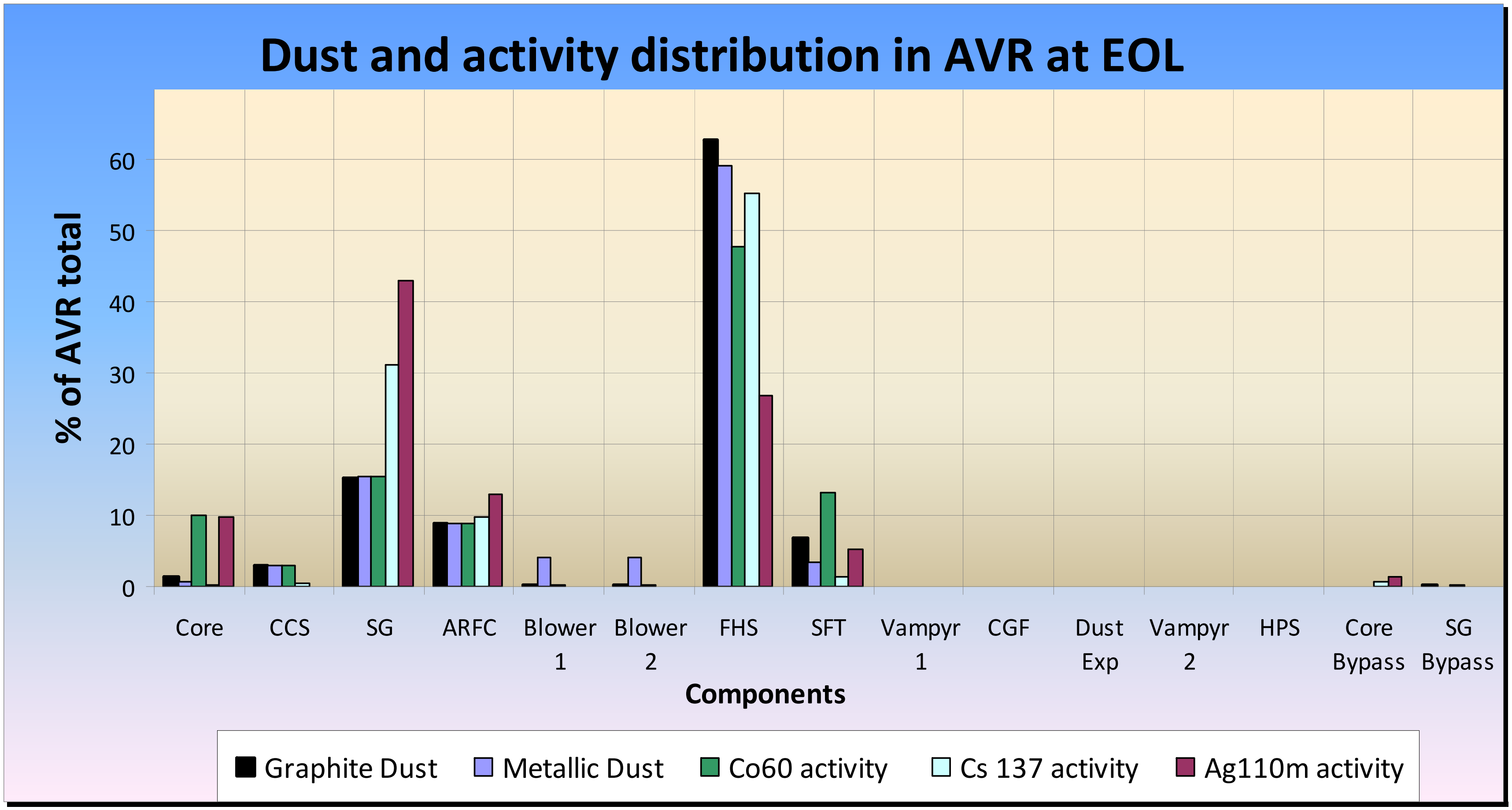



% Plate-out in AVR primary circuit low due to surfaces covered with dust, except in high flow areas with reduced dust coverage

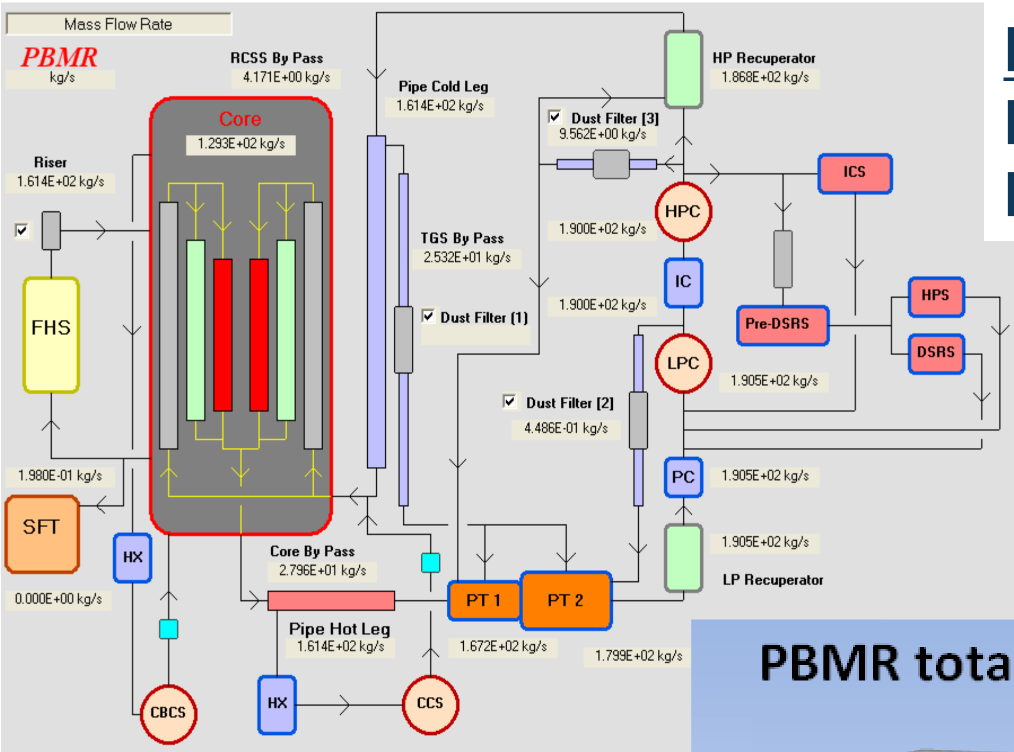
% Plate-out in Vampyr I experiment high due to insertion of clean tube at start of experiment; graphs are a function of temperature effects governing dust – F.P. interaction

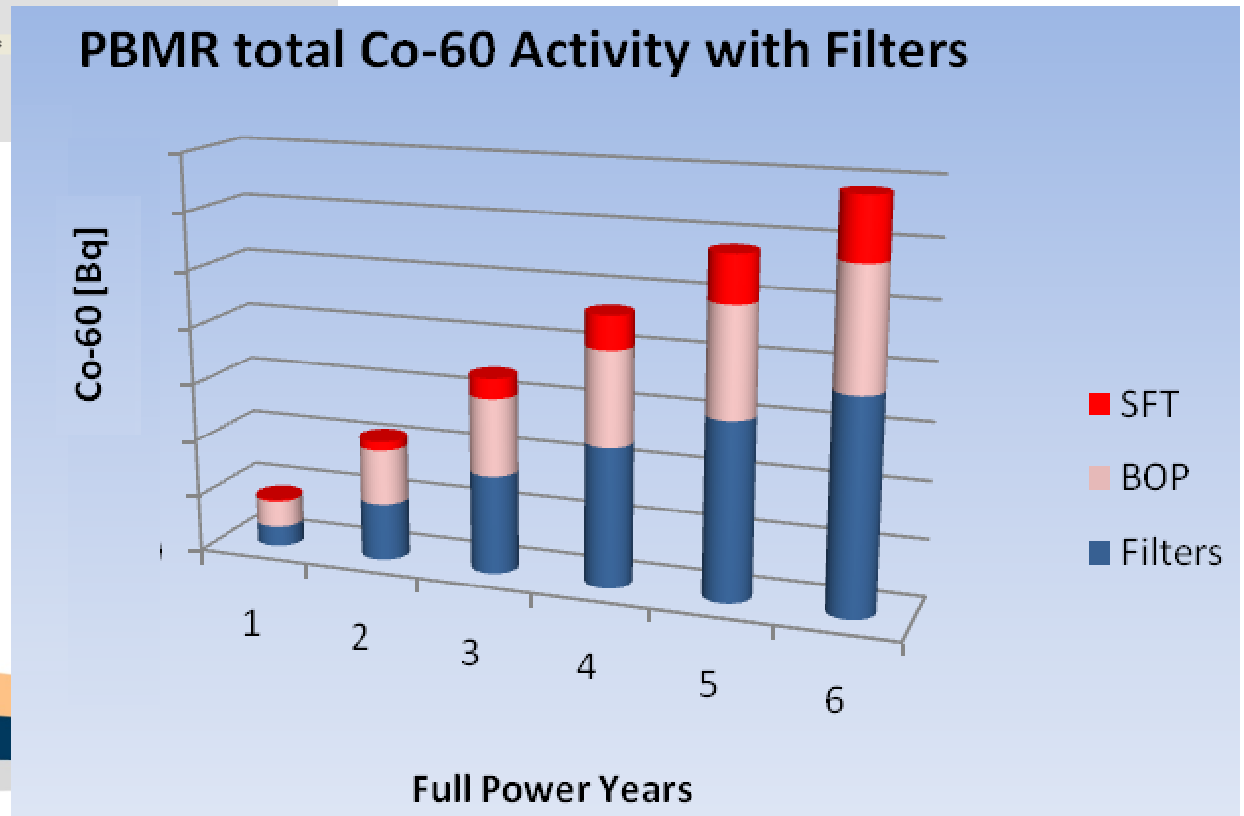


# DAMD distribution of graphite & metallic dust, Co60, Cs137 and Ag110m activity in AVR



# DAMD as PBMR Design Tool
# Example: 60Co Dust Activity Distribution



# Data Requirements Stemming From DAMD Development

- Integrated effects data:
  - A code that models full plant migration of dust, fission and activation products must take integrated effects in the whole plant, including the core and fuel handling system, into account to model accurately. Dust deposition/lift-off and fission product plate-out cannot be considered separately.
- Separate-effects data:
  - Separate-effects dust deposition tests in simple configurations like pipes are required for evaluating deposition models in selected areas of integrated plant models.
- Dust migration through attachment to fuel spheres:
  - This is a driving force for the distribution of dust, fission and activation products in a pebble-bed plant.
  - Experiments for testing the migration of dust on fuel spheres would be useful for validation of an integrated code like DAMD.

# PBMR Code Verification and Validation (V&V)

- FP and dust transport Code V&V requires specific data
  - data must be relevant to phenomena and conditions modelled
  - depends on modelling approach
- SPECTRA (bottom-to-top) approach requires:
  - data from separate effects, combined effects, and fully integrated effects experiments
- DAMD (top-to-bottom) approach requires:
  - specific inputs, eg.
    - dust generation data, dust classification (metallic and graphite)
    - dust mass retention in core and fuel handling system
  - identification of important phenomena to be modelled explicitly, vs as lumped parameters
  - data from separate and combined effects experiments

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# Potential Value of PSI facility for PBMR

- Data of interest:
  - graphite and metallic dust classification or morphology
  - core dust generation mechanisms
  - validated core dust generation models
  - dust migration data (in-core and balance of system)
  - operational effects of dust (clogging, heat transfer efficiency)
  - ranked phenomena regarding dust generation and transport
  - deposition and resuspension validation data and models
  - data from both separate effects and integrated effects experiments

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THANK YOU.

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