Experience from the Application of the Dry Filtered Method for Filtered Containment Venting to Several Plant Designs

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Dry Filter Method Basics

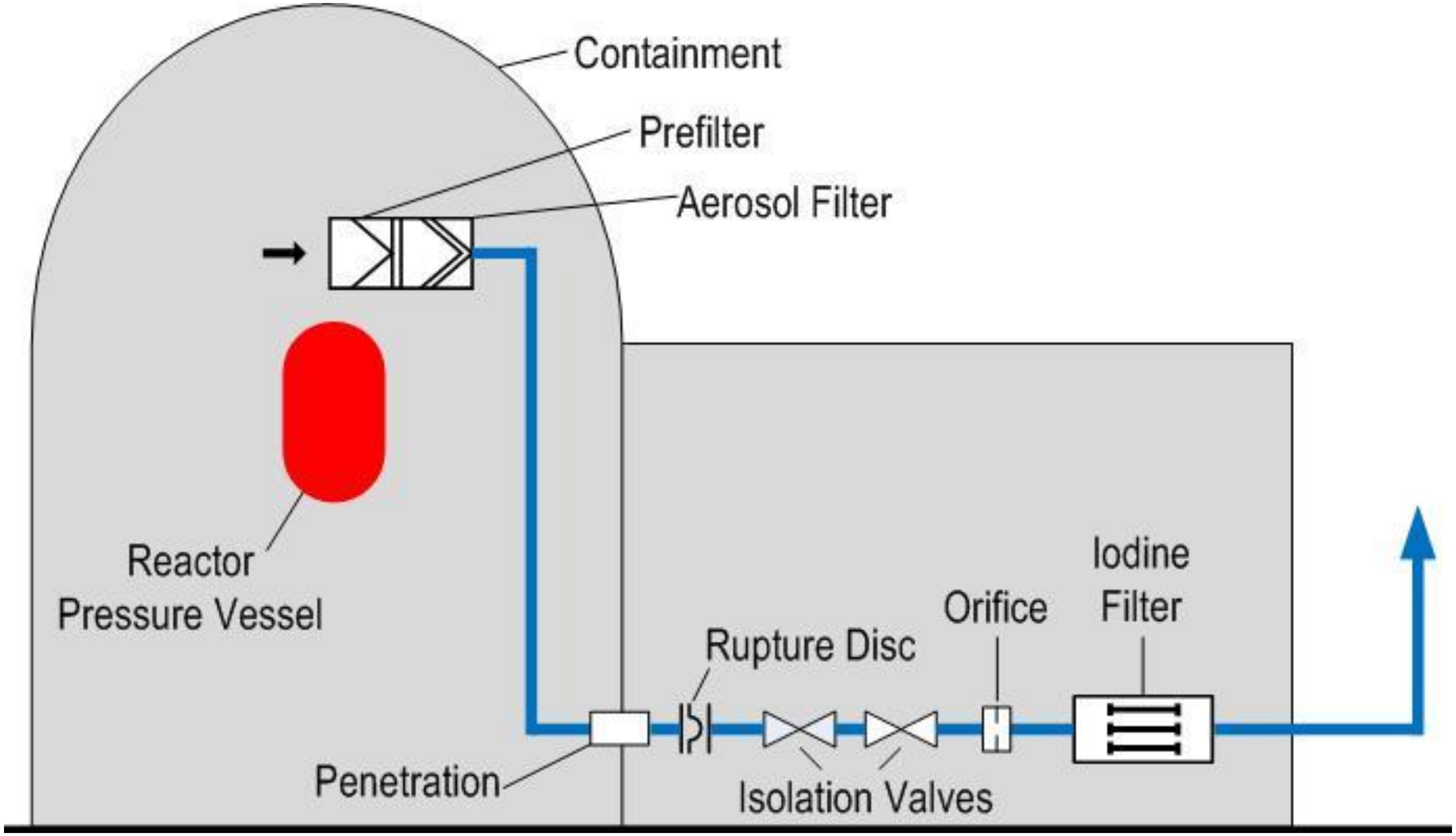
Two major passive filter components:

1. Aerosol Filter (deep bed metal fiber filter):
   Removal of solid particles (aerosols) – e.g. CsI, CsOH
2. Iodine Sorption Filter (molecular sieve with zeolites):
   Removal of elemental iodine (I_2) and organic iodine (CH_3I, etc.)

Two variants of the dry filter method have been qualified:

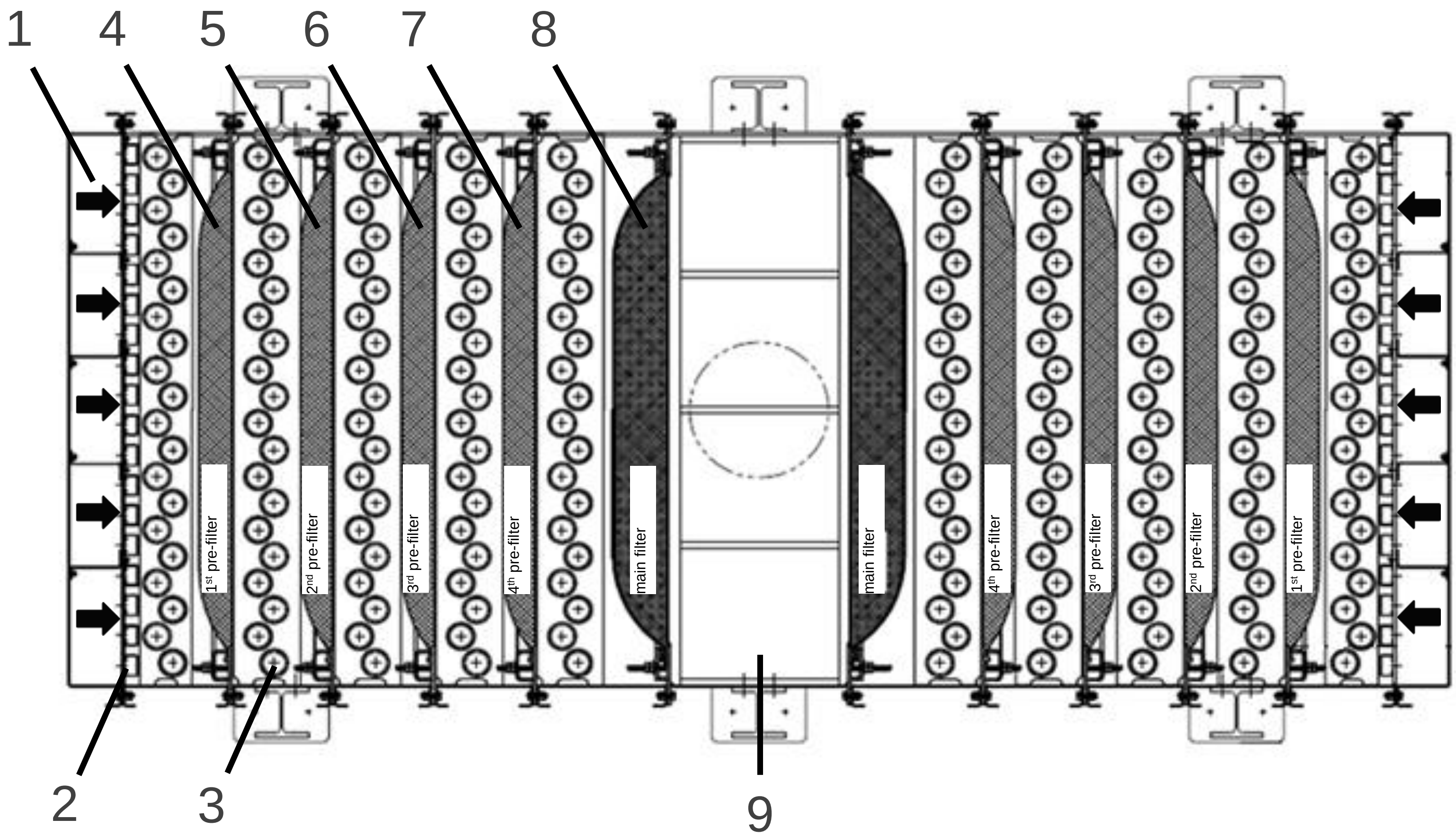
- Different location of the aerosol filter
  1. Inside containment (long lived aerosols never leave containment)
  2. Outside containment (combined aerosol and iodine filter)
- Iodine Sorption filter always outside of the containment (short lived I-131)

Dry Filter Method: Inside Containment Configuration Overview



Dry Filter Method: Inside Containment Configuration Aerosol Filter Unit

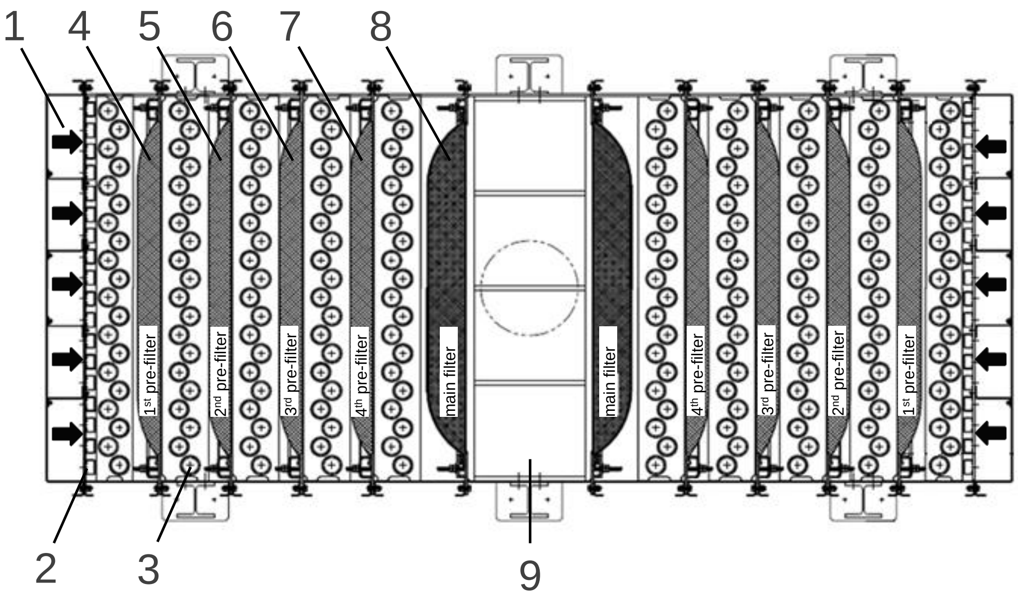
Example of an Aerosol Filter – Top View



1 Inlet
2 Droplet Separator
3 Cooling Tube
4,5,6,7 Pre Filter
8 Main Filter
9 Outlet

Dry Filter Method: Inside Containment Configuration Aerosol Filter Unit

Example of an Aerosol Filter – Top View

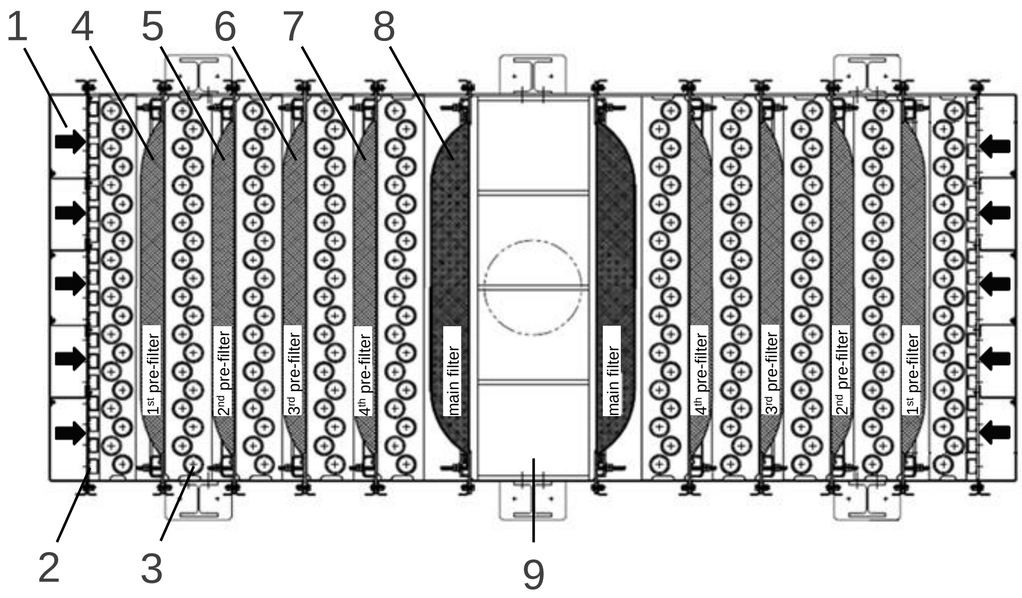


Metal fibres

Cooling Tube

Dry Filter Method: Inside Containment Configuration
Aerosol Filter Unit

Example of an Aerosol Filter – Top View

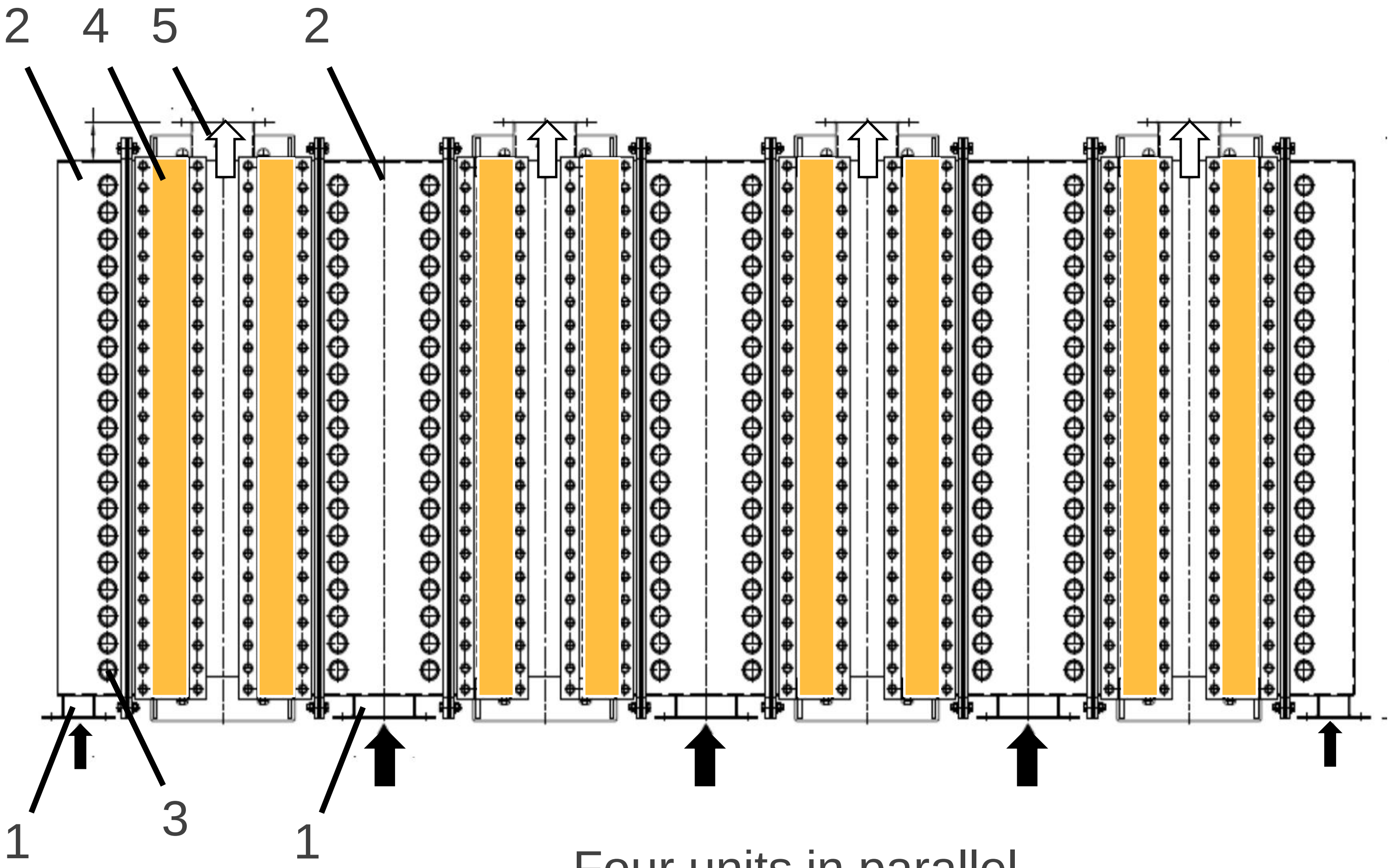


1	Inlet
2	Droplet Separator
3	Cooling Tube
4,5,6,7	Pre Filter
8	Main Filter
9	Outlet

- Metal fibers in the filter stages decrease in diameter over the module
- Main function of the pre-filter is to provide storage space for large aerosol loading capacity
- Very high specific surface area of the fine (main) filter provides high retention even for smallest particles with very high efficiency
- Big advantage: Use of the existing containment shield wall for protection of aerosol filters against external events and for radiation shielding

Dry Filter Method: Inside Containment Configuration
Iodine Filter Unit

Example of an Iodine Filter – Top View

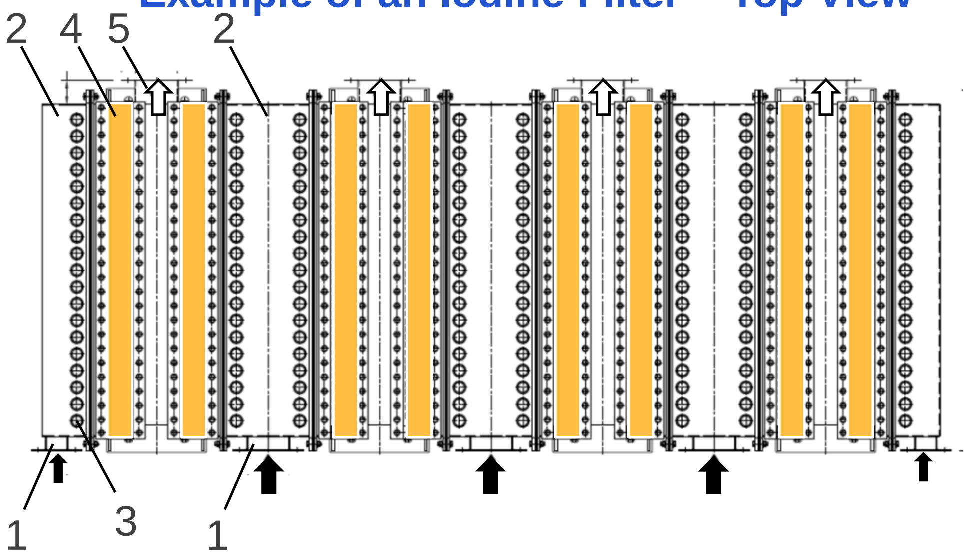


1	Feed Pipe
2	Inlet Chamber
3	Cooling Tube
4	Zeolite Bed
5	Exhaust Duct

Four units in parallel

Dry Filter Method: Inside Containment Configuration Iodine Filter Unit

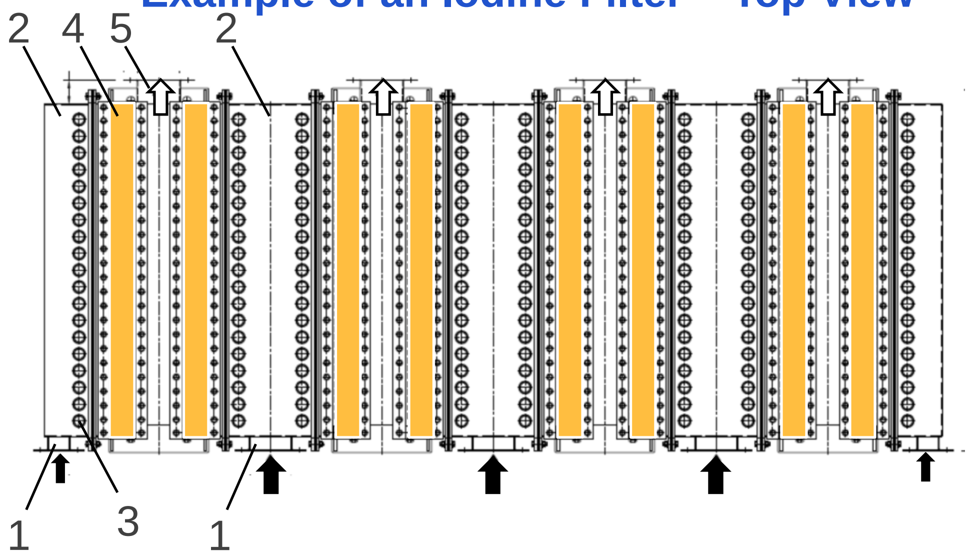
Example of an Iodine Filter – Top View



Example of zeolite filter material (diameter ~1 mm)

Dry Filter Method: Inside Containment Configuration
Iodine Filter Unit

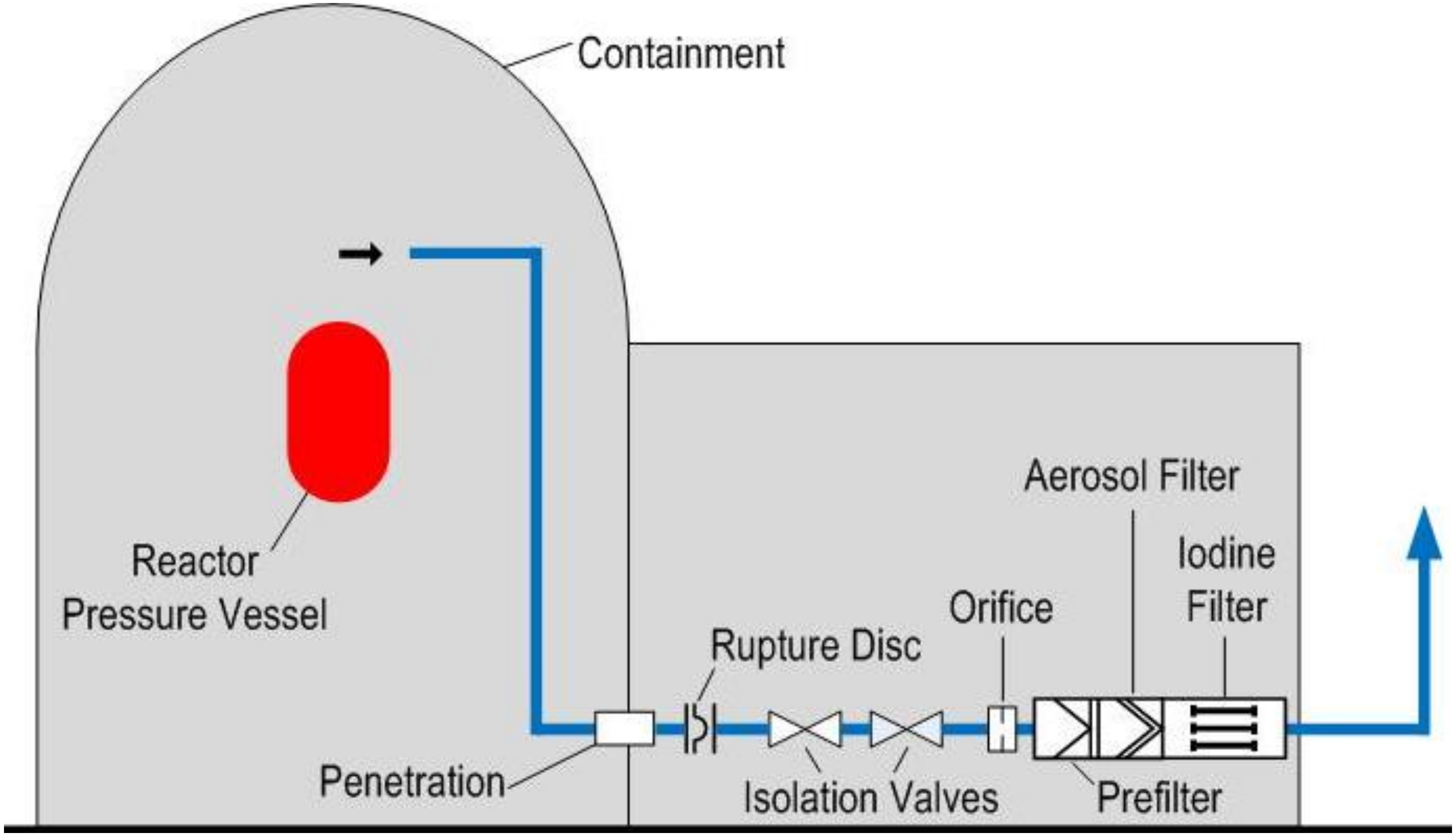
Example of an Iodine Filter – Top View



1	Feed Pipe
2	Inlet Chamber
3	Cooling Tube
4	Zeolite Bed
5	Exhaust Duct

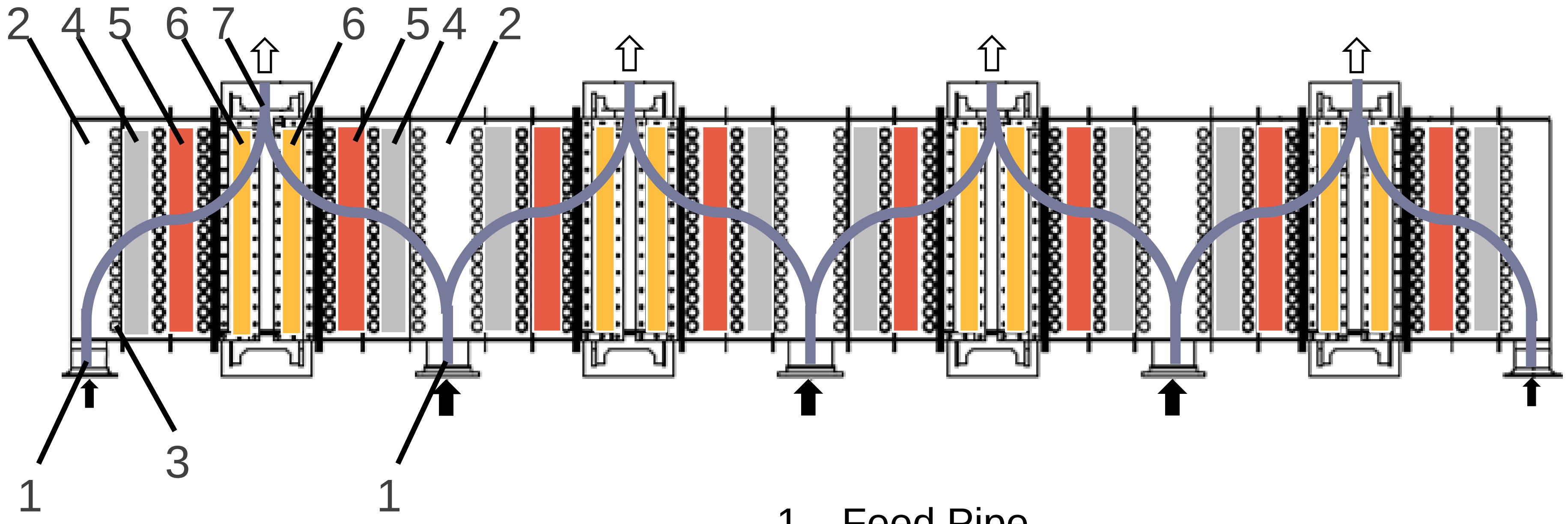
- Adsorption material is composed of small beads of silver doped zeolite
- Chemisorption of gaseous iodine: Ag + I → AgI
- Decontamination factor (DF) depends on residence time and distance to the dew point
- Effective filter area and bed depth of the zeolite are designed to meet
  - the retention requirements for elemental and organic iodine for the whole venting process and
  - the decay heat requirements

Dry Filter Method: Outside Containment Configuration Overview



Dry Filter Method
Outside Containment Configuration – Combined Filter

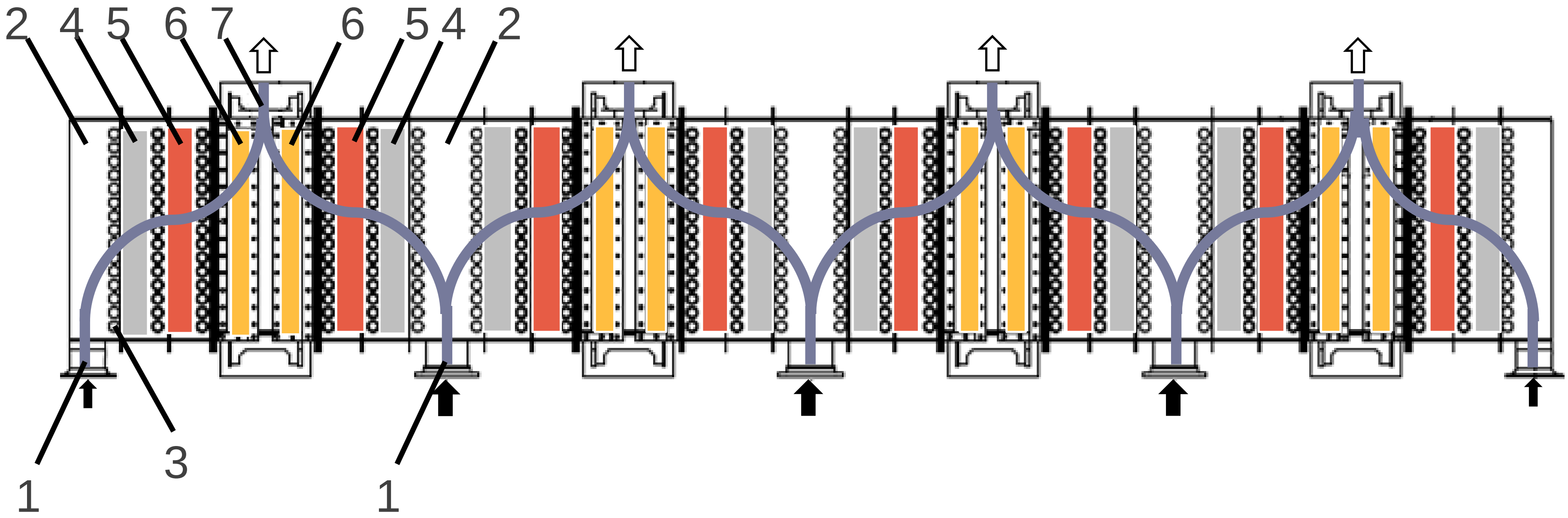
Example of a Combined Aerosol/Iodine Filter – Top View



1	Feed Pipe
2	Inlet Chamber
3	Cooling Tube
4	Pre Filter
5	Main Filter
6	Iodine Filter
7	Exhaust Duct

Dry Filter Method
Outside Containment Configuration – Combined Filter

Example of a Combined Aerosol/Iodine Filter – Top View



- Filter principles: the same as for the inside containment configuration
- Combined housing contains both, aerosol and iodine filter
- Again: <u>Modular</u> Design

Dry Filter Method References

- DFM with aerosol filter **inside** containment:
  - NPP Biblis A and B (delivered in 1990 and installed in 2002)
  - NPP Mülheim-Kärlich (1991)
  - NPP Krško (2013)
  - NPP Ohi 3&4 (under development)
  - NPP Sizewell B (under development)
- DFM with aerosol filter **outside** containment :
  - NPP Brokdorf (1986 and 2002)
  - NPP Grohnde (1990)
  - NPP Unterweser (1990)
  - NPP Stade (1990)
  - Darlington Nuclear Generating Station (under development)
- Furthermore: Iodine filter for complementing a wet scrubber Containment Filtered Venting System under development

Application to Several Plant Design Regulatory Requirements (1)

- No internationally standardized regulatory requirements for CFVS
- Different "types" requirements in different countries, for example:

Country	Requirement
Germany	Aerosols DF=1,000 Elemental iodine DF=10 Organic iodine DF= not specified
Finland	Atmospheric release of cesium-137 < 100 TBq
Sweden	Atmospheric release of Cs-134 and Cs-137 < 0.1 % of the core inventory for 1,800 MWth reactor

Application to Several Plant Design Regulatory Requirements (2)

- Besides the regulatory requirements with respect to retention of radioactive material:
  - Site specific requirements (e.g. earthquake) and
  - Plant specific requirement (e.g. space restrictions)
- Based on the plant design and regulatory requirements the functional requirements of the DFM have to be developed
- Typically, the functional requirements of the CFVS are derived from severe accident analyses.

➢ The DFM is sized to fulfill this functional requirements

➢ **Functional requirements** for the limiting accident scenarios should be **developed early in the project!**
Reason: Huge influence on system design!

Application to Several Plant Design Functional Requirements: Examples

Parameter	NPP Krško	NPP Ohi (3&4)	NPP Darlington
Reactor type	PWR	PWR	Candu
DFM configuration	In-containment	In-containment	Out-containment
DF aerosol	1,000	10,000	1,000
DF org. iodine	10	40	5
DF elem. iodine	100	1,000	200
Aerosol mass load	30 kg	5 kg	100 kg
Mass Flow at start of venting	7.0 kg/s	12.1 kg/s	25.0 kg/s
Decay heat capacity of aerosol filters	170 kW	20 kW	970 kW
Decay heat capacity of iodine filter	20 kW	100 kW	24 kW

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1 DFM system per unit

1 DFM system for 4 units!

Application to Several Plant Design Design Parameters – Aerosol Filter

General aspects:

- Factory acceptance tests shows excellent DFs for the main filter stage (>100,000) with the conservative test aerosol Uranine
- DFM is a very robust technology, capable of seismic loads e. g. for Japanese NPPs with accelerations of up to 20 G and higher
- Number of metal fiber mats inside the modules, fiber diameters, and the packing fractions do not depend on the individual application
=> No need for special dimensioning of these parameters

- Besides the seismic qualification the aerosol filter has to be sized to meet the following functional requirements:
  - Required venting mass flow
  - Specified aerosol mass load
  - Specified decay heat load

Application to Several Plant Design
Design Parameters – Aerosol Venting Mass Flow

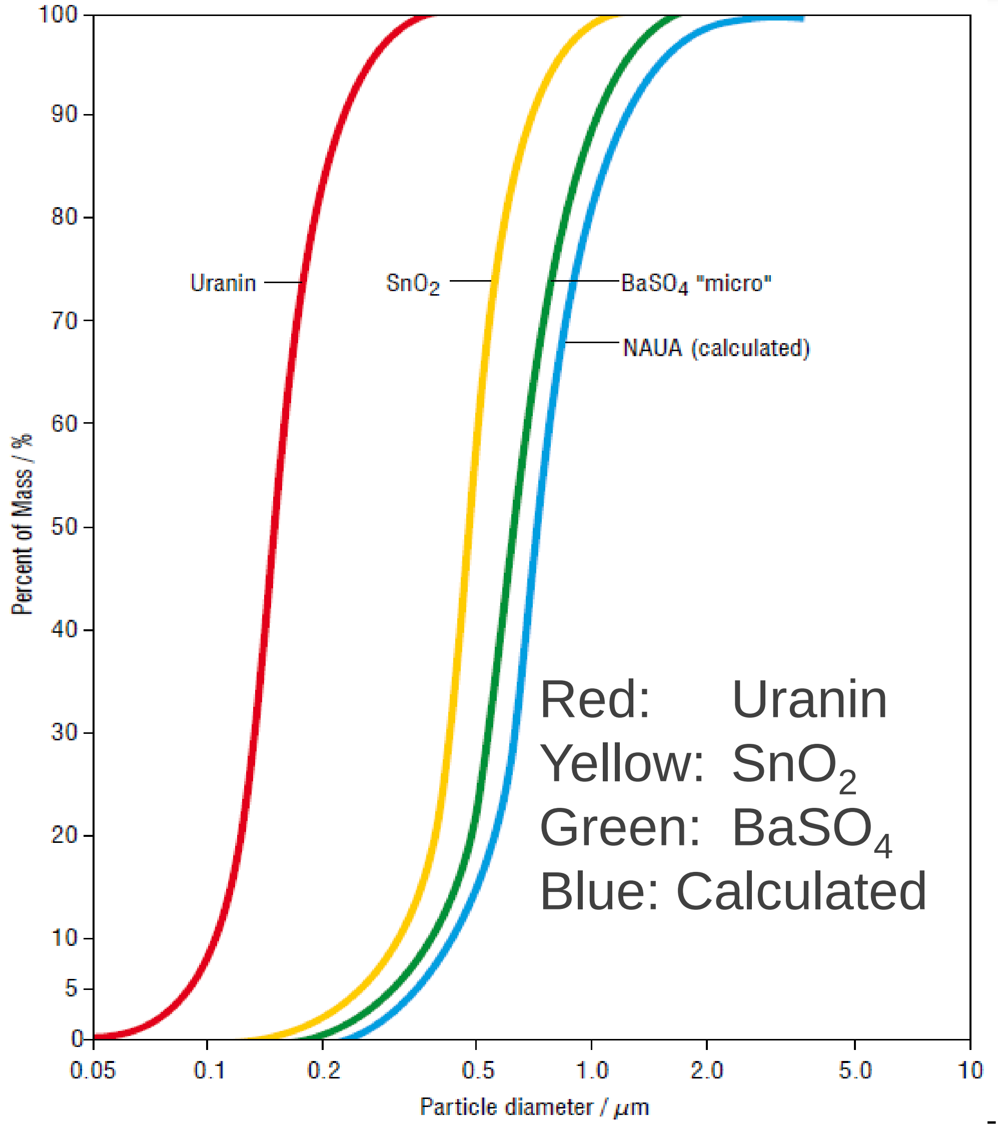
- Venting mass flow defines the minimum required filter cross section
- Higher cross section is achieved
  - by parallel configuration of several filter units inside containment or
  - by assembling several filter modules at the combined filter
- As the combined filter is arranged after the orifice a larger filter area is required than for the stand-alone aerosol filter inside the containment

- Example: Three different minimum required filter cross sections

Design Parameter	NPP Krško	NPP Ohi (3&4)	NPP Darlington
Minimum required filter area	10.6 m^2	8.9 m^2	117.5 m^2

Application to Several Plant Design
Design Parameters – Mass Load (1)

- The aerosol load capacity and the corresponding pressure drop of the aerosol filter are derived from loading tests with SnO_2 and $BaSO_4$
- SnO_2 is used as reference aerosol
- Graph shows size distribution of test aerosols and simulated size distribution of aerosols to be expected in severe accident



Red: Uranin
Yellow: SnO_2
Green: $BaSO_4$
Blue: Calculated

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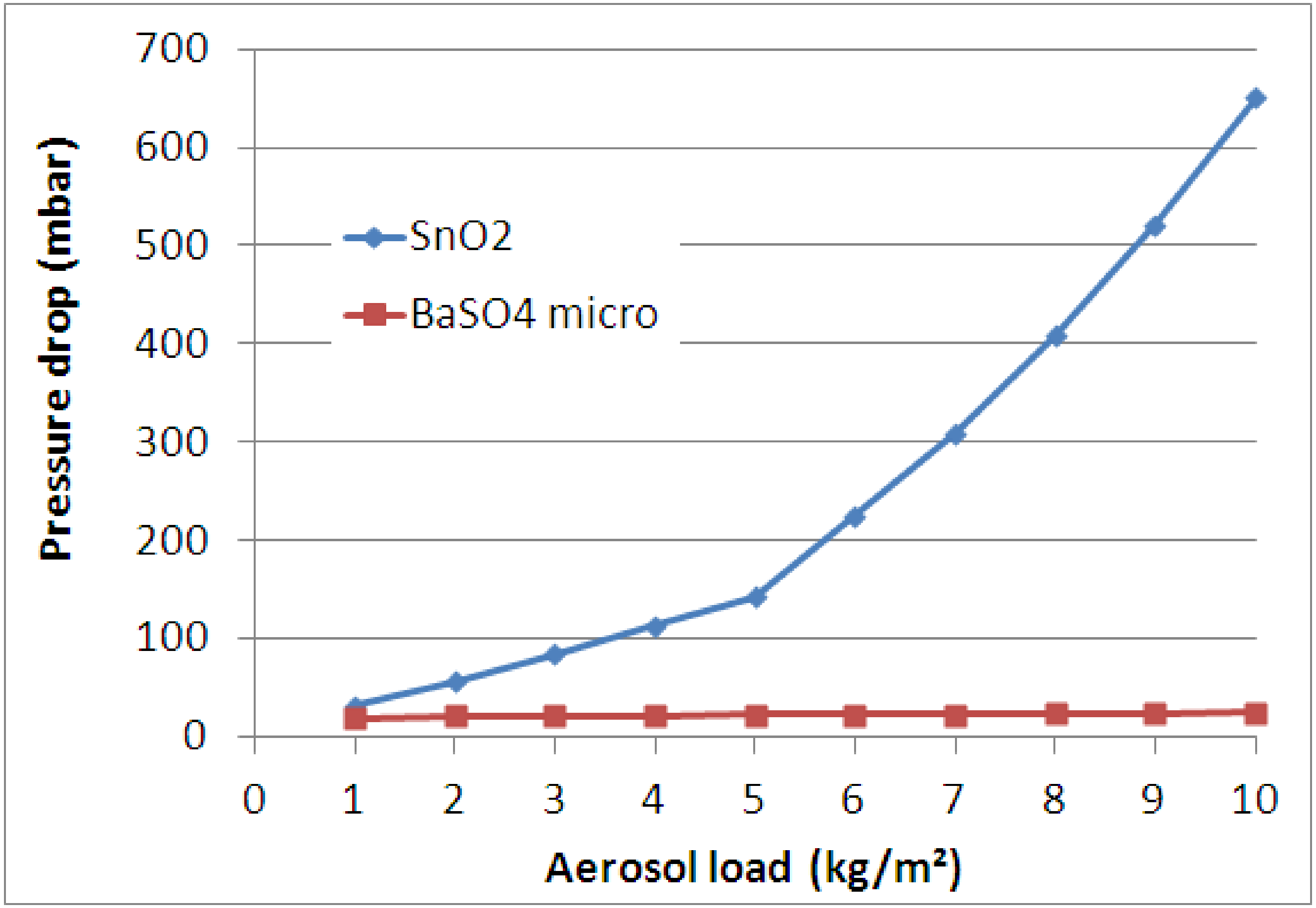
Application to Several Plant Design
Design Parameters – Aerosol Mass Load (2)

- SNO_2 is conservative test aerosol.
  Hence large margin against clogging



Application to Several Plant Design Design Parameters – Decay Heat (1)

- The acceptable design limit temperature of the metal fibres is 823 K (550 °C)
- The heat removal capacity of the aerosol filter can be increased by
  - Additional cooling tubes
  - Increasing filter area
  - Increasing the number of aerosol filters/modules
  - Partition of the pre-filter stage with additional cooling module

Application to Several Plant Design Design Parameters – Decay Heat (2)

- Consideration of heat deposition by gamma rays:
  Gamma energy represents approximately 76% of the total decay heat
- A radiation analysis for an aerosol filter shows that approx.
  - 4% of the fission product gamma radiation is converted into heat load in the filter stages and
  - 66% of gamma energy is adsorbed in the filter housing and internal metallic support structures
  - Hence about 30% of the gamma energy leaves the filter housing
- This results in an effective reduction of the heat load to the aerosol filter of about 25 %

Application to Several Plant Design
Design Parameters – Scaling heat load capacity (1)

Example of scaling the heat load capacity of a combined aerosol/iodine filter unit

	Increase in housing length	Removal Capacity w/o consideration of gamma "escape"	Removal Capacity w consideration of gamma "escape"
Initial design:	0 mm	185 kW	246 kW
Initial design with zigzag arranged cooling tubes	280 mm	190 kW	253 kW
Additional cooling tubes in front of pre-filter,cooling tubes arranged linear	800 mm	555 kW	738 kW

Application to Several Plant Design
Design Parameters – Scaling heat load capacity (1)

Example of scaling the heat load capacity of a combined aerosol/iodine filter unit

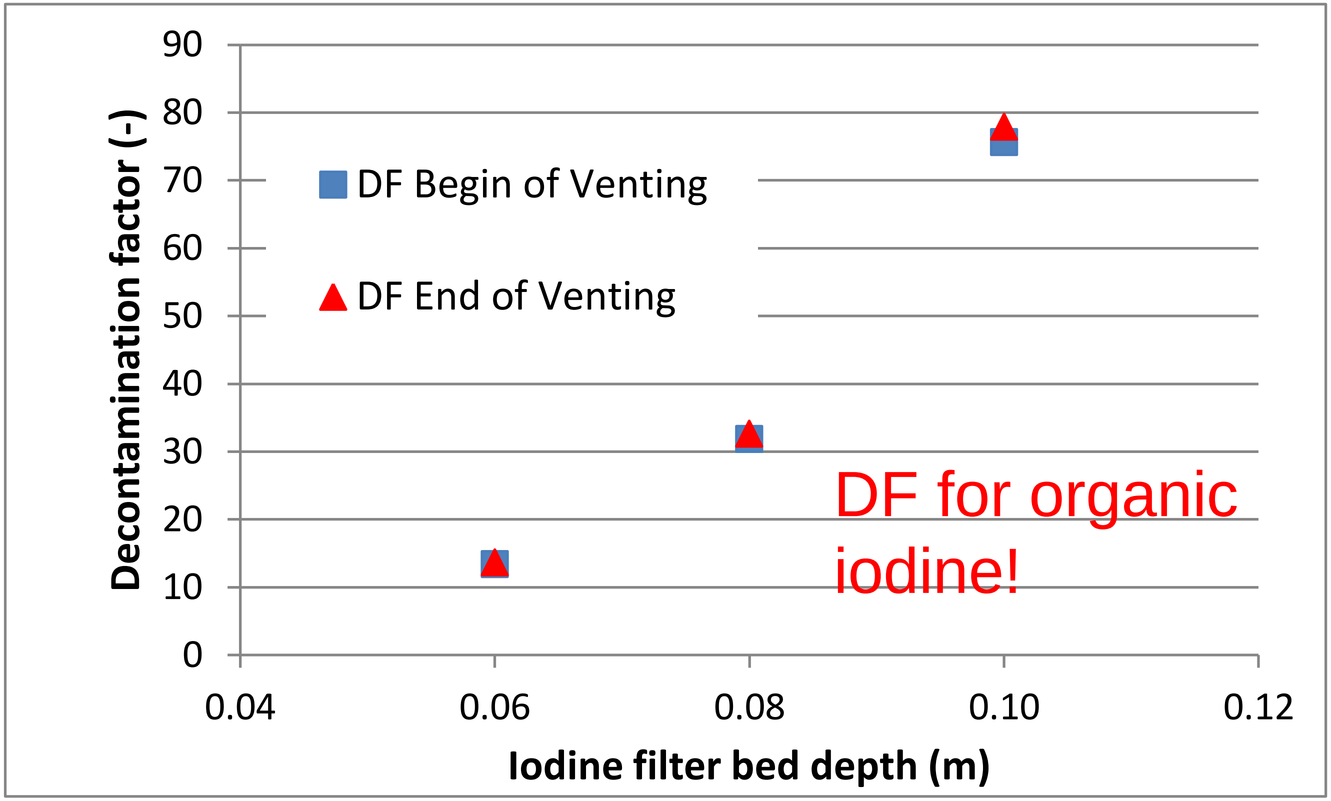
	Increase in housing length	Removal Capacity w/o consideration of gamma “escape”	Removal Capacity w consideration of gamma “escape”
Initial design:	0 mm	185 kW	246 kW
Additional cooling tubes in front of pre-filter,cooling tubes zigzag arranged	1000 mm	600 kW	798 kW
One additional filter stage (2nd pre-filter), all cooling tubes zigzag arranged	2600 mm	1000 kW	1330 kW

Application to Several Plant Design Design Parameters – Iodine Filter

- The iodine filter will retain the gaseous iodine (organic and elemental) from the vented gas flow
- The DF is dependent on the residence time and the distance to the dew point
- The minimum required filter area is determined by the volume flow
- By increasing bed depth and/or filter area, the residence time increases and thus any required DF can be achieved
- The DF of zeolite for elemental iodine is much better than for organic iodine thus the required DF for elemental iodine is usually covered by the DF for organic iodine
- The zeolite iodine filters withstand temperatures up to 773 K (500 °C)
- The heat removal capacity can be increased like for the aerosol filter, by: Adding additional cooling tubes, additional filter modules or increasing filter area

Application to Several Plant Design Design Parameters – Iodine Filter

- The DF stays almost constant during the whole venting process: Decreasing dew point distance and increasing residence time compensate each other



Key Observations Design/Fabrication/Installation (1)

- Filter functional requirements for the limiting accident scenarios should be developed early in the project

- Integrated design and analysis of the system, filters, components and piping are essential for successful project execution.

- For inside containment configuration the iodine filter layout should consider using existing concrete wall for shielding
  Reason: Construction of a separate shield wall is complex and heavy and should be avoided if possible

Key Observations Design/Fabrication/Installation (2)

- Use of the existing containment shield wall for protection of aerosol filters against external events and for radiation shielding is a big advantage

- Installation of aerosol filters and associated piping inside containment can be done during the refueling outage without impacting the overall outage schedule and this despite the very limited space inside the containment

- Modular design of filters is key to the possibility of retrofitting the system into existing plant structures

- In situ assembly of filter modules is simple and fast

Summary (1)

- Since the first applications in Germany an additional DFM system was installed at NPP Krško, Slovenia, and several other DFM projects are under design
- The experience of these projects is used to continuously improve the DFM

- A CVFS based on DFM technology is robust against earthquake and can be easily scaled to different regulatory, plant and site specific requirements

- The required DF for aerosol has not to be sized individually, it is fixed
- The required (any required) DF for gasous iodine can be met, for instance by varying the zeolite bed depth, etc.

Summary (2)

- By using SnO_2 as conservative reference aerosol for the determination of pressure drop behavior, the filters have large margin against clogging
- The heat load capacity of the aerosol filter and iodine filter can be adapted to plant specific requirements by increasing the filter area, adding additional cooling tubes/modules or partition of the pre-filter stage with additional cooling module
- Integrated design and modularity of the system are key to making optimal use of existing plant structures, thus minimizing cost and effort of installation