Filtered Containment Venting System

NRC Public Meeting, September 4th 2012
Rockville, MD

IMI Nuclear (CCI AG)

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- How it works
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- Installed Filtered Containment Venting System (FCVS)
- Sizing
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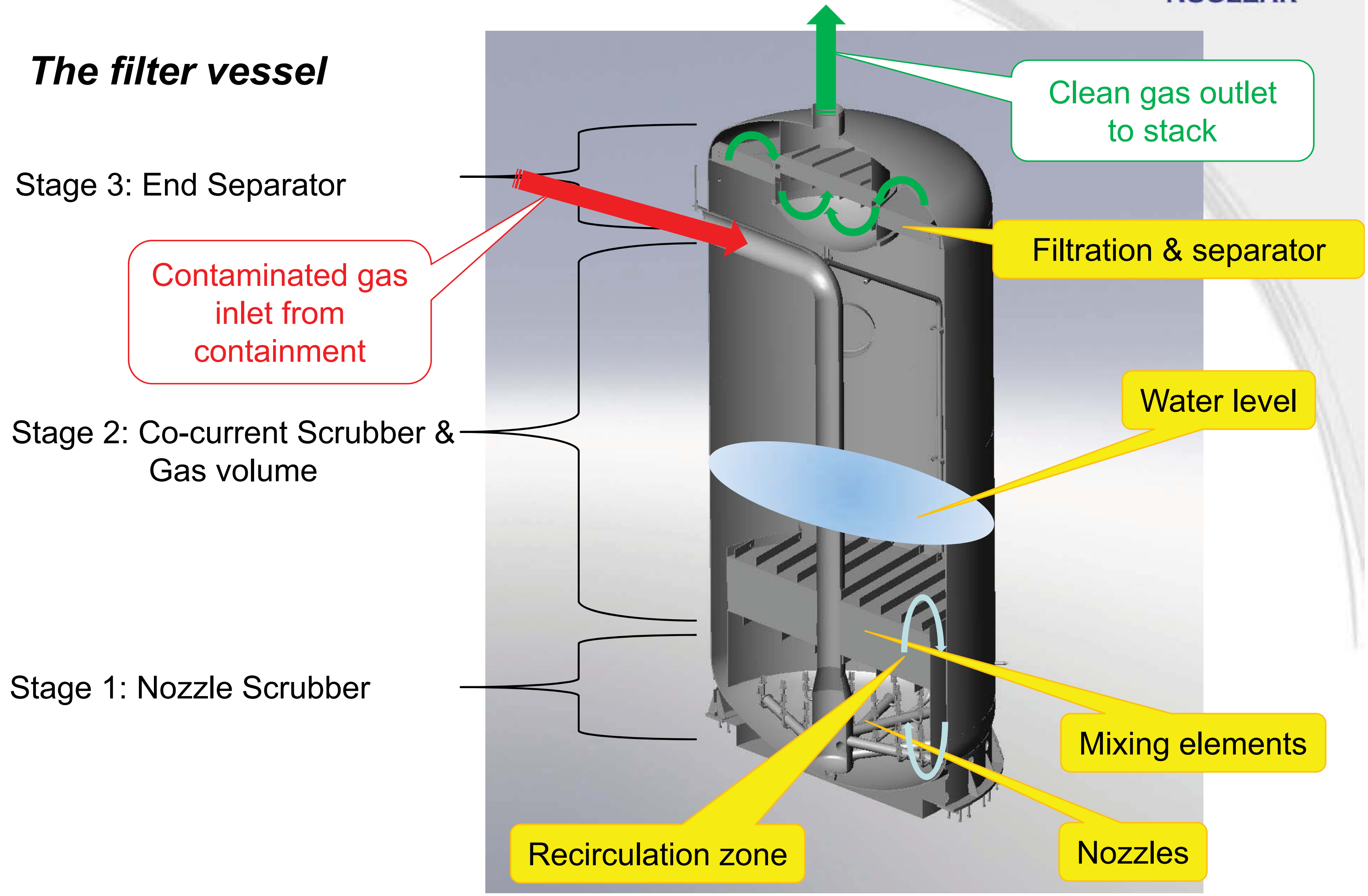
Overview

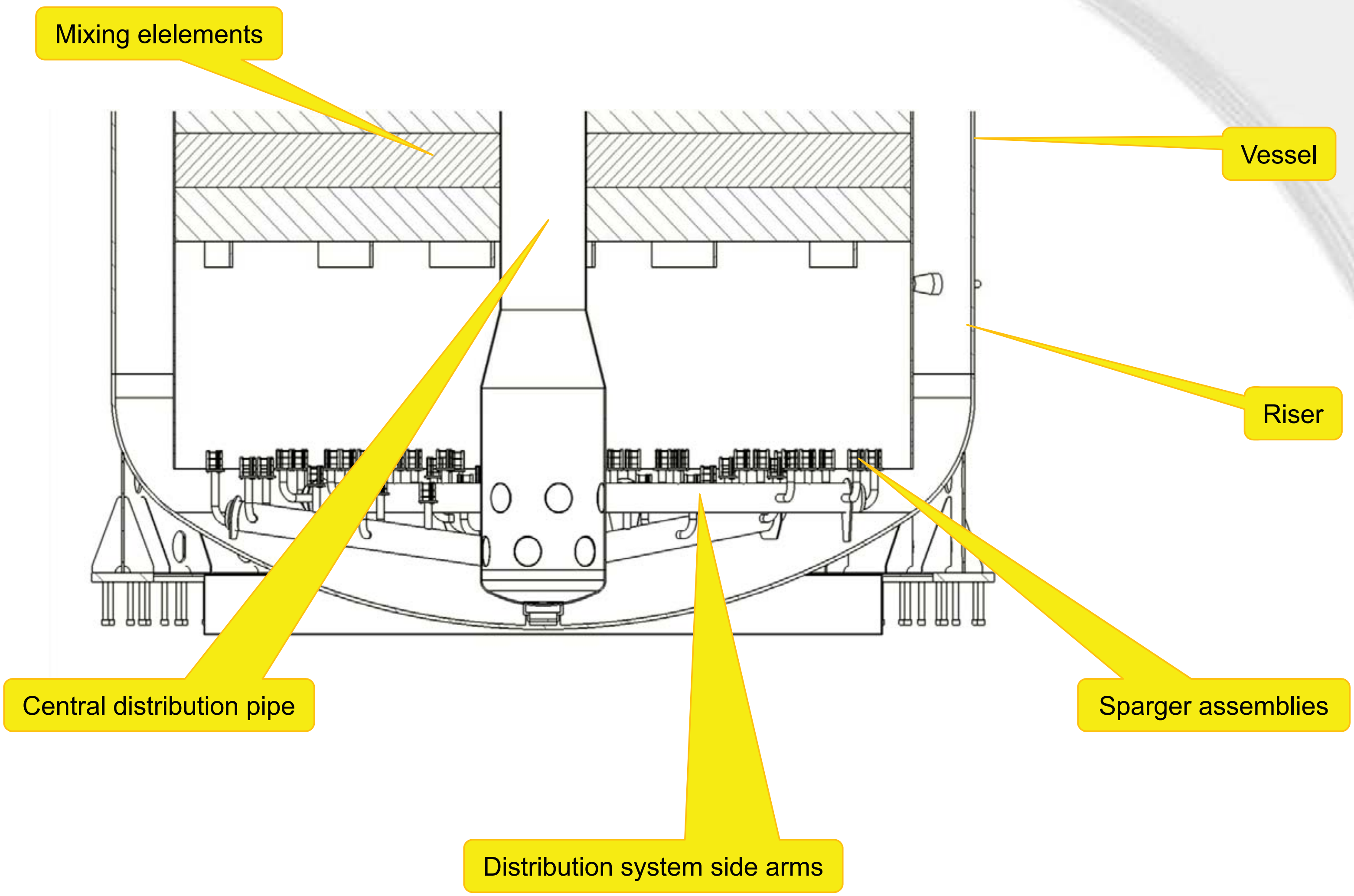
- The problem: The core damage scenario might require depres-surization (venting) of the containment
- The solution: A first generation of filtered containment venting system (FCVS) has been installed on approximatly 120 reactors worldwide
- A second generation of FCVS with a unique filtering efficiency has been developed by CCI and is ready for implementation
- Safety authorities and utilities have expressed interest to the proposed technology

How does it work?

The filter vessel



How does it work – Stage 1, Nozzle scrubber



How does it work – Stage 3, end separator

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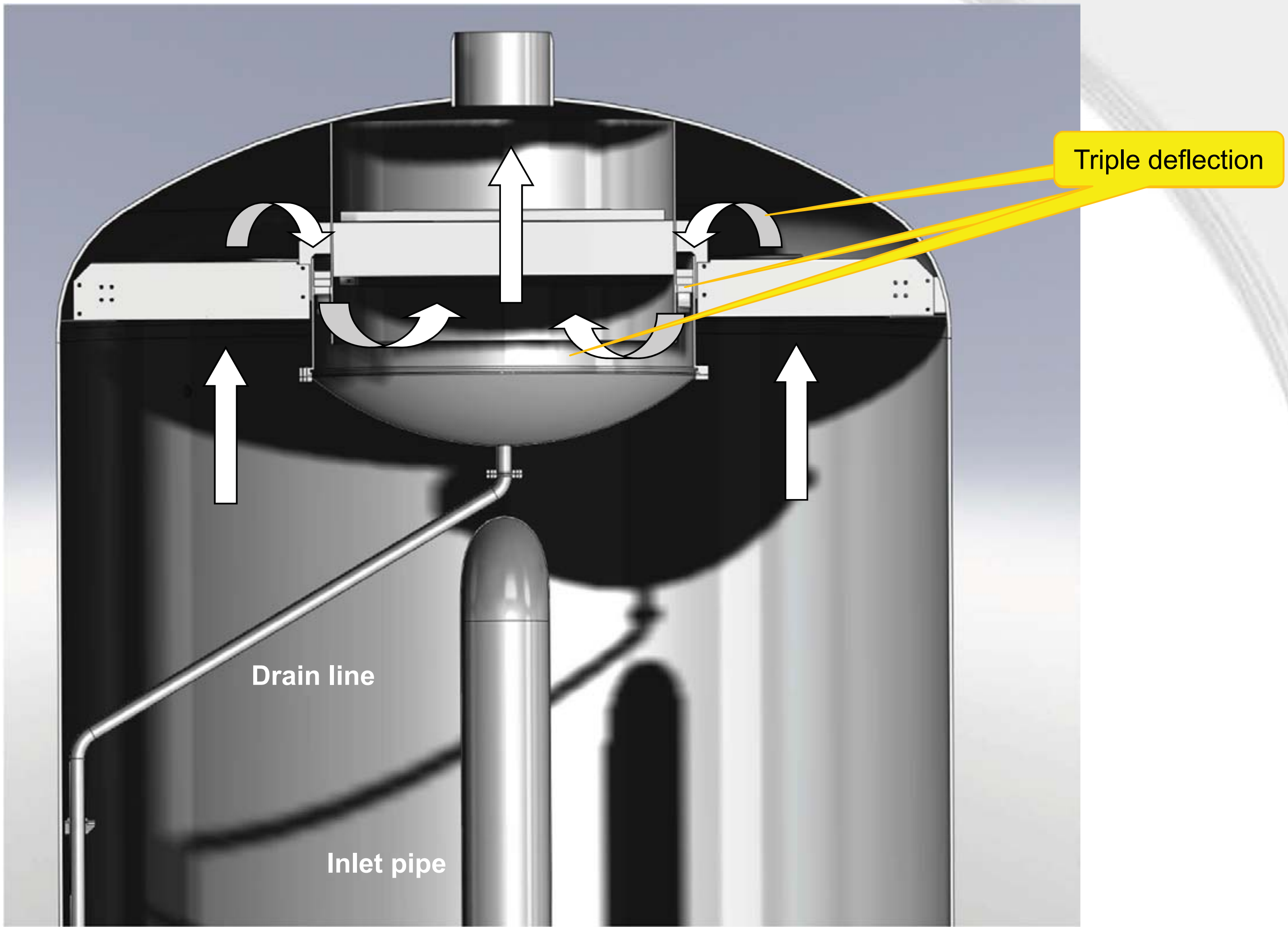

How does it work – Summary

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First Stage

- Efficient scrubbing by flow injection nozzle with special baffle plates:
  - disintegrating gas jet
  - strong turbulence for high mass and heat transfer
  - distribution of gas bubbles over whole cross section
  - Efficient bubble break-up
- Specified depressurization rate defined by flow limiting nozzle
- Arrest any flame propagation from containment by the water in the filter
- *Excellent decontamination for mid to high flows*

Second Stage

- Co-current scrubber within the core section increases mass transfer
- Large residence time through trapped bubbles in recirculation zone
- Gas volume for water level variation and suppression of droplet carry-over
- *Excellent decontamination for mid to low flows*
- **Chemistry to scrub and fix volatile iodine species unique to 2nd generation**

Third Stage

- Droplet separator

How does it work – Chemistry

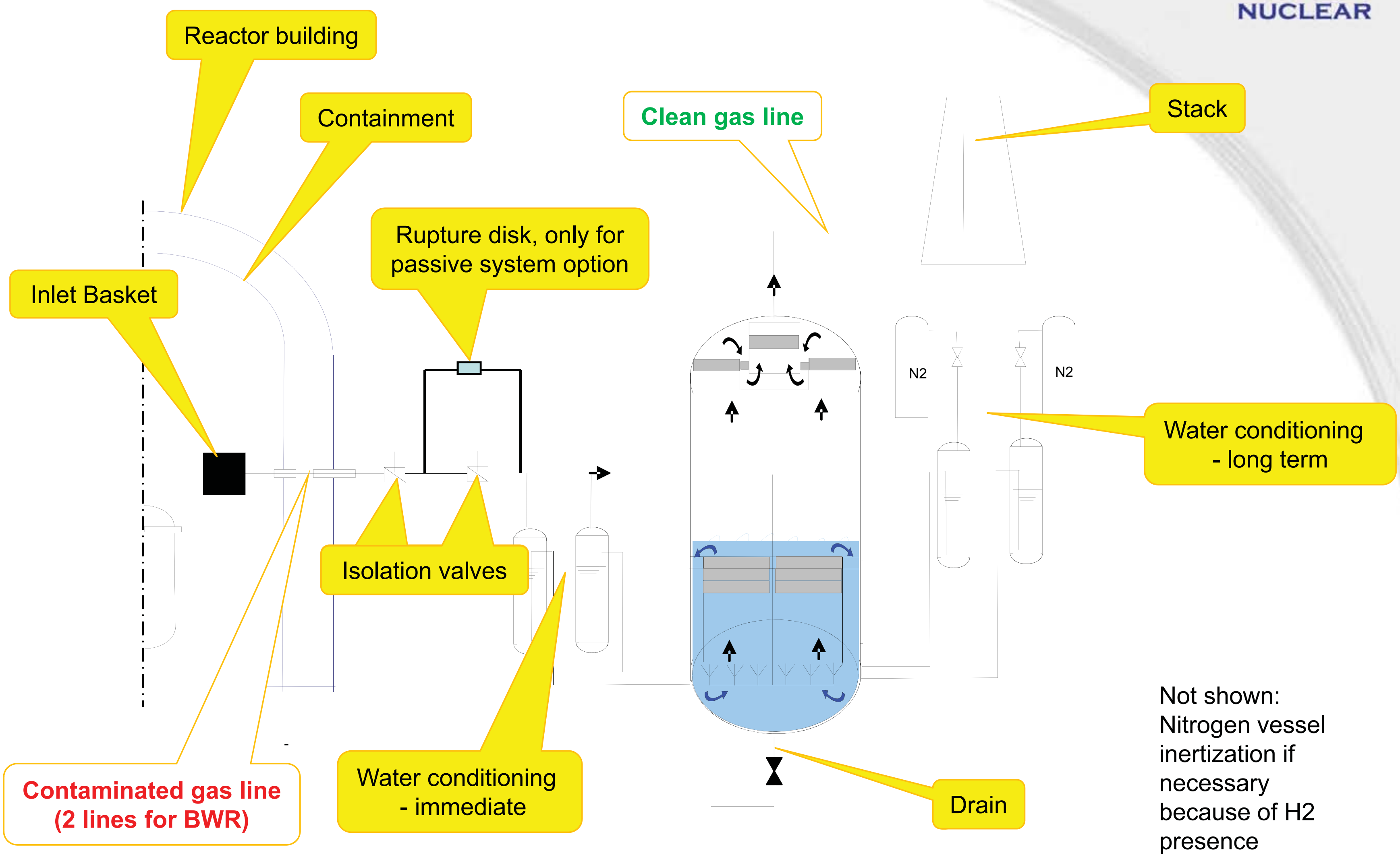
Efficient retention of iodine species in an aqueous solution with two processes occurring simultaneously and starting with the operation of the system:

1. **Faster reduction** (decomposition to I-) of all iodine species, especially the most volatile ones, with any oxidation level entering into the solution or generated in the solution into iodide ions by simultaneous use of a reducing agent (sodium thiosulfate) and a co-agent (phase transfer catalyst)
2. **Efficient retention** of iodide ions generated in the aqueous solution and/or entering into the solution in form of iodine salts **by suppressing the thermal and radiolytic oxidation (re-volatilization) of iodide ions by the use of the co-agent**

These faster reduction and retention processes are efficient at any state of the aqueous solution; strong acidic to strong basic solutions, cold to very hot solution, and under irradiation. **This allows for a long term retention of all iodines species in the filter vessel**.

The combination of fast reduction AND retention of iodines (patent granted) is the unique feature of the 2nd generation FCVS

How does it work – Layout



Not shown:
Nitrogen vessel inertization if necessary because of H2 presence

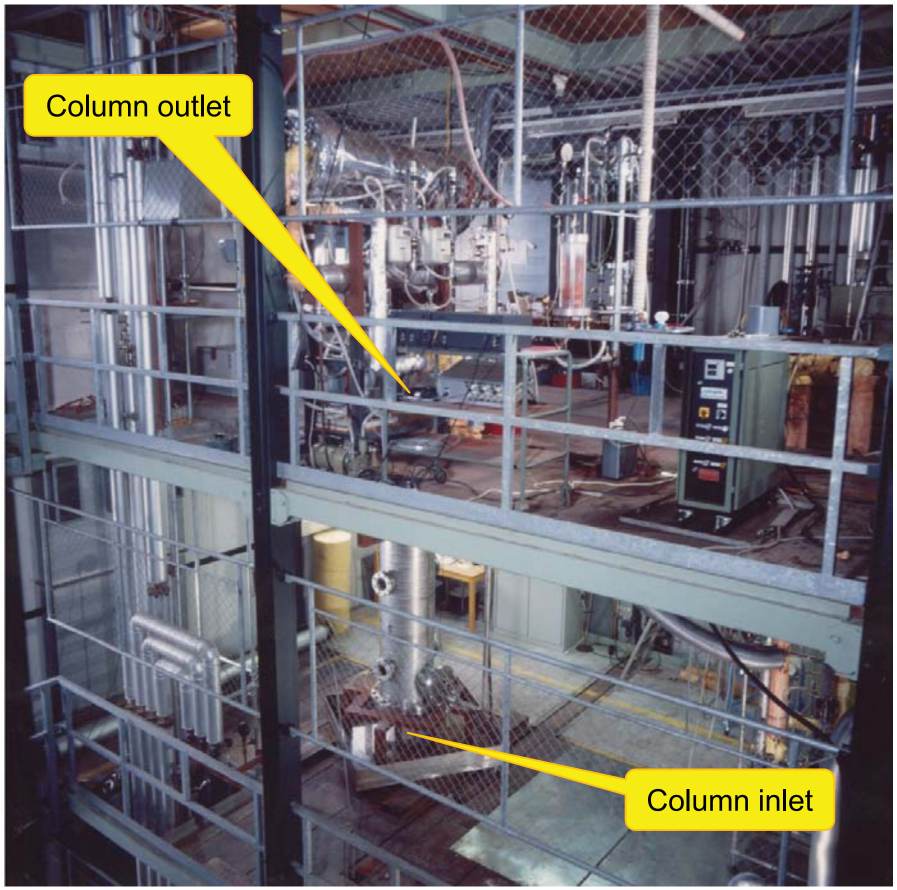
Experimental data base

R&D on FCVS – a short History

- CCI developed a FCVS in the 1980 time frame based on:
  - Extensive SULZER Experience in Filtration systems on:
    - Concurrent scrubbers (mixing elements) and distillation columns
    - SULZER mixing and filtration elements
- An extensive development and qualification program was conducted at SULZER in the late 1980's and the early 1990's
- Verification tests and further qualification tests were conducted at the Paul Scherrer Institute (PSI) during 1994 to 2003
- Absolute retention of all gaseous iodine activity: Tests series with new chemistry dedicated to obtain fast and efficient destruction of volatile iodine species from 2002 to 2008

Experimental data base – Initial R&D

Aerosol test loop used for initial development and qualification <1993



Basic Testing of filtration Elements:

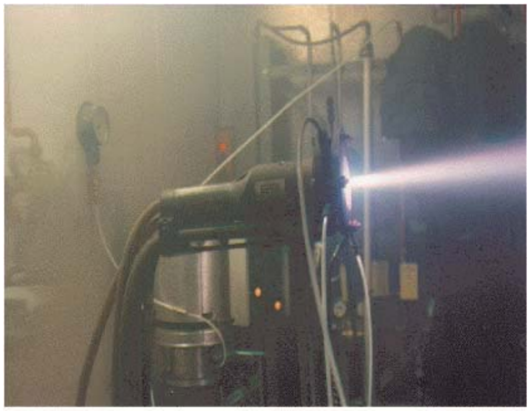
- Nozzles
- Co-current mixing elements
- Droplet separator

Full Scale Segment Testing:

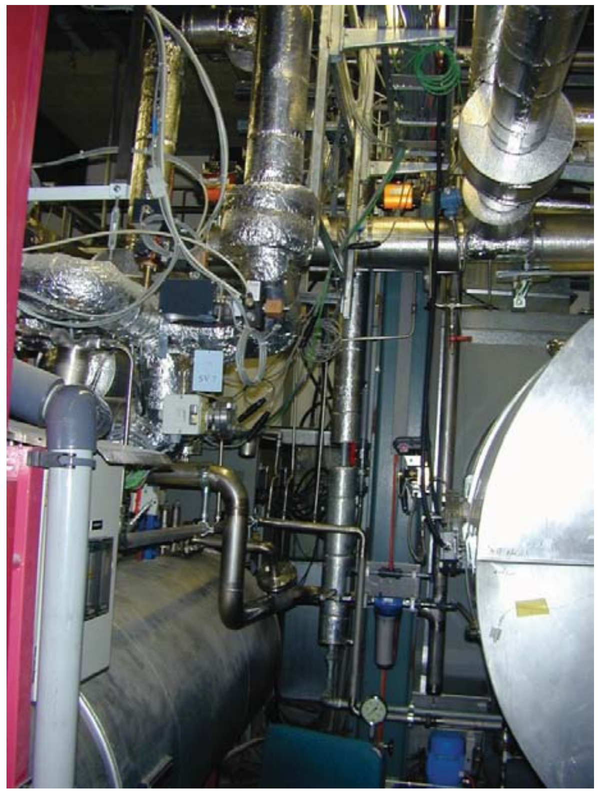
- Filter qualification and variation of main parameters such as flow, temperature, aerosols
- Re-suspension (and clogging) of last stage

Experimental data base – Verification & further tests

Test loop used for Further Qualifications for Aerosol Retention at PSI (1993-1995)



Plasma used to evaporate tin powder. After condensation of tin vapor, SnO_2 particles are generated



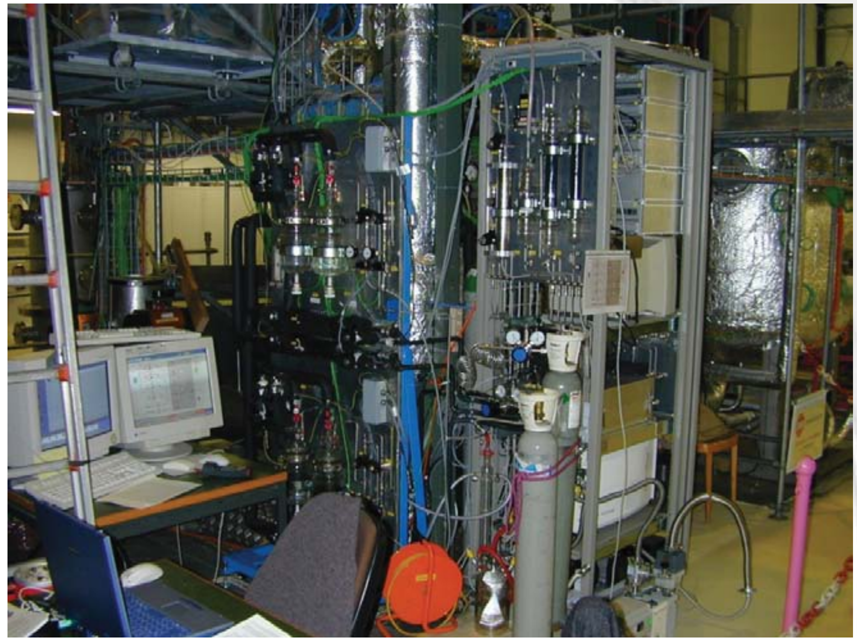
Facility to prepare aerosol laden steam-gas mixture flow

A representative module of FCVS filter used for aerosol tests

Experimental data base – Iodine retention tests

Qualification test for gaseous iodine species retention (2000 – 2002)

Iodine species generation and feed system



Iodine species on-line/grab sampling measurement system

No high retention of methyl iodide and I_2 obtained but finally…

Experimental data base – Iodine retention tests

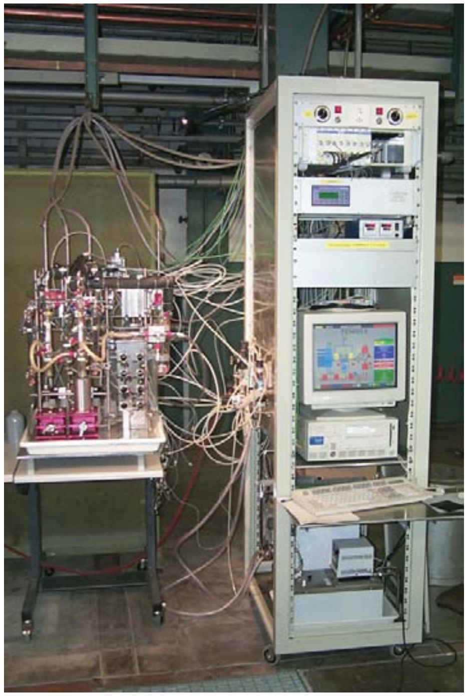
..the way to success with mastering iodine retention chemistry (2002 – 2008)

- Mastering iodine chemistry in aqueous phase to
  - Obtain fast and efficient destruction of volatile iodine species to iodide ions (methyl iodide representing all high volatile organic iodide species and I_2 for all other gaseous species)
  - Fix iodide ions to suppress their radiolytic and thermal oxidation
- Over 1000 tests conducted using I_2 and CH_3I covering:
  - Very acidic to strong basic solutions
  - Room to high solution temperature
  - A large range of initial CH_3I concentrations
  - A large range of individual and coupled usage of both additives
  - Effect of other impurities (irradiation products, fission products, etc.)
  - Small to large dose
  - Effect of in situ β-irradiation and external γ-irradiation
  - Static and dynamic systems
  - Effect of additives on the aerosol scrubbing

…with specially developed measurement techniques to follow chemical reaction products

Experimental data base – Iodine retention tests

Influence of radiation on iodine retention



Reaction vessel in the γ-irradiation chamber and gamma-cell

Reaction vessel, apparatus for distillation and activity control systems as well as the remote control units are ready for the transfer to the hot cell for in-situ β irradiations

Experimental data base – Conclusions of the tests (I)

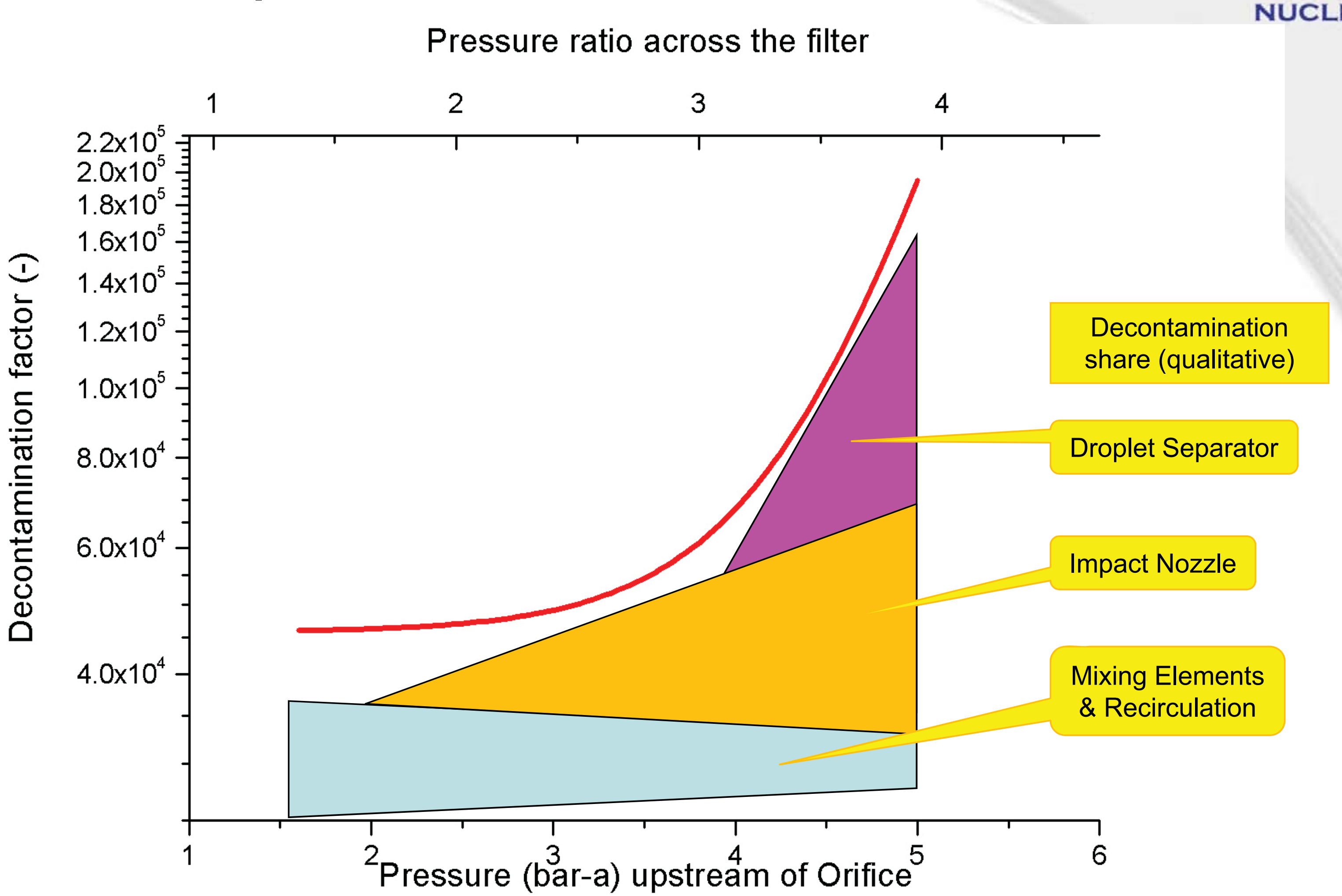
- **Activity retention,** overall **minimum** decontamination factors (DF):

for the 2nd generation FCVS:		in comparison with 1st generation FCVS requirements:
Aerosols	**» 10‘000**	**> 1‘000**
Elemental iodine (I_2)	**> 1’000**	**> 100**
Organic iodide (CH_3I)	**> 1’000**	**none!**

In the following operational conditions:

- **Flow rate** ratio of **larger than 10**
- **Multiple venting** possible – no release of fission products (desorption, re-vaporization) because FP trapped in filter water only
- **Post venting** – no long term release of fission products **including iodine(s) bound** in filter water (re-volatilization) because of chemical binding
- No filter **clogging and hot spot** risk
- DF valid with low pH (3), all temperatures including boiling conditions, sub-micron to micron particle size, highest filter load

Experimental data base – Results



Experimental data base – Results

➢ <u>Permanent sink for iodide ions </u>enabling absolute iodine retention

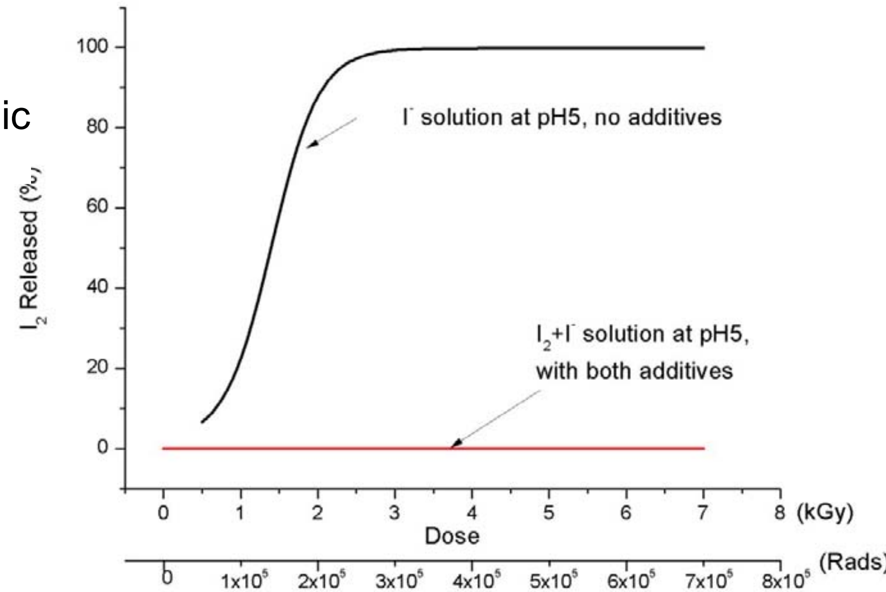
Source of iodide ions in FCVS:

- aerosols: scrubbed metallic iodides (CsI)
- gaseous: scrubbed elemental iodine and organic iodide

Test data shows no free iodide ions available in the water due to effective fixation reaction by the co-agent …

…therefore, thermal and radiolytic oxidation of iodide ions to volatile I2 does not occur

➔ **Re-volatilization of iodines does not occur**



Experimental data base – Conclusion of the tests (II)

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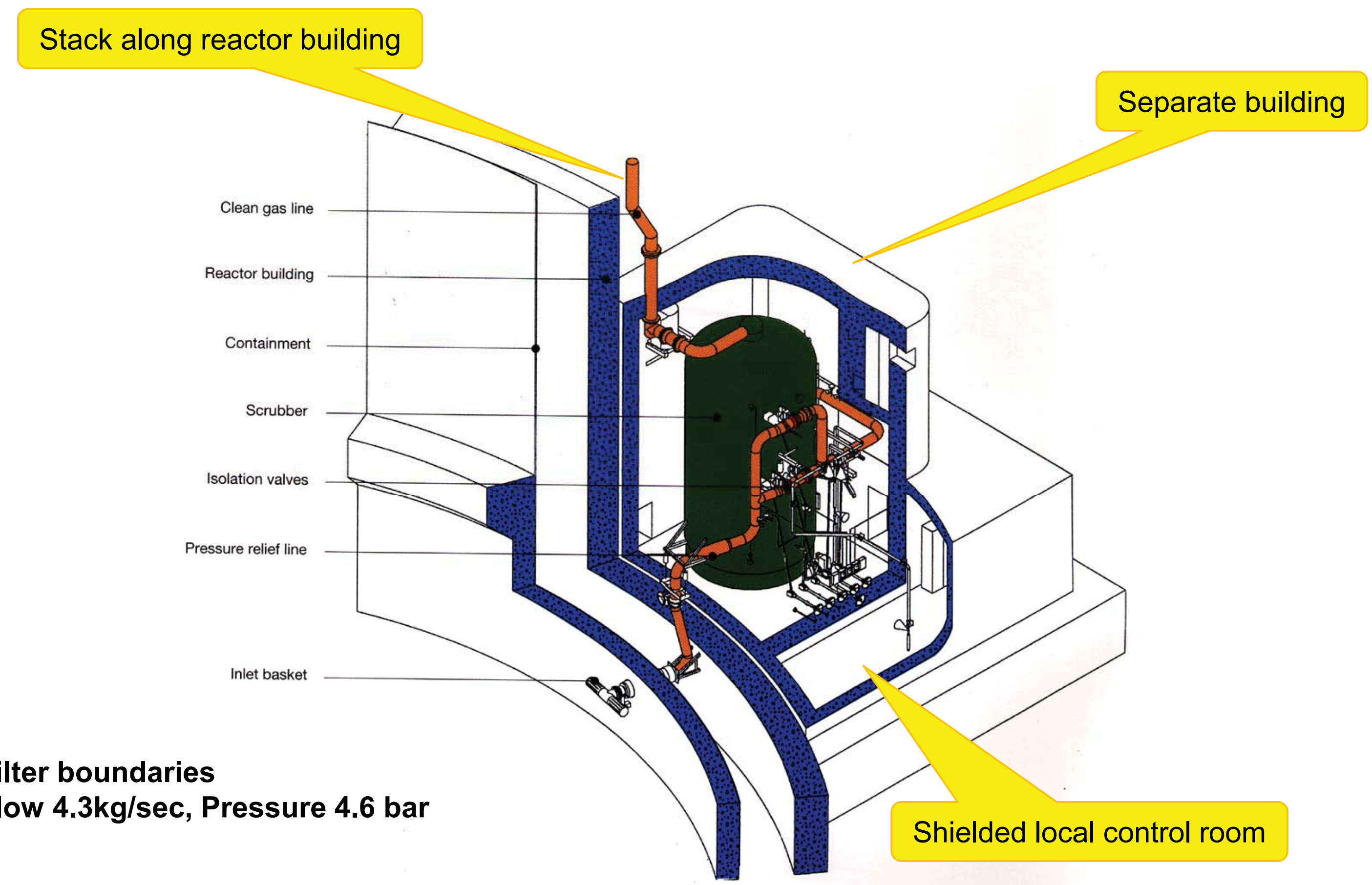
Improvements of filtration from 1st to 2nd generation

Accident Phase	Relevant, volatile Nuclids	Spec. Retainment Factor for FCVS Gen. 1		Spec. Retainment Factor for FCVS Gen. 2	
		conservative	best estimate	conservative	best estimate
Phase 1: **short term** retainment capacity after first ventings of scrubber /filter containers	Cs 134/137-aerosols	Min .1'000	>200'000	**Min. 10'000**	>200'000
	I-131 organic	**1**	**<5**	**Min. 1'000**	**>1'000**
	I-131 elementary	100	100	**Min. 1'000**	**>1'000**
	I-131-aerosols	Min .1'000	>200'000	Min. 10'000	>200'000
Phase 2: **long term** retainment capacity after several ventings of scrubber /filter containers NEW CONSIDERATION! FROM R&D	Cs 134/137 – aerosols	Min. 1'000	>200'000	**Min. 10'000**	>200'000
	I-131 organic	**1**	**<5**	**Min. 1'000**	**>1'000**
	I-131 elementary	**1**	**<5**	**Min. 1'000**	**>1'000**
	I-131-aerosols	**1**	**<5**	**Min. 10'000**	**>200'000**

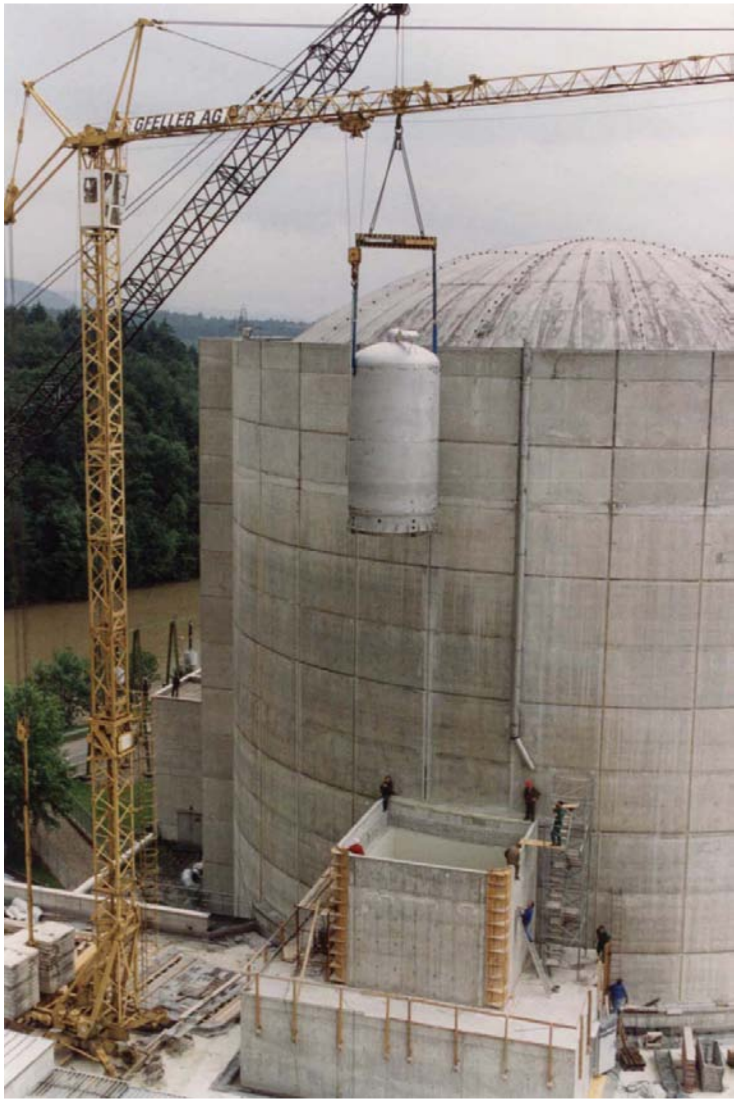
Installed IMI FCVS

Beznau Nuclear Power Plant – Layout for Westinghouse 2 loops PWR



Filter boundaries
Flow 4.3kg/sec, Pressure 4.6 bar

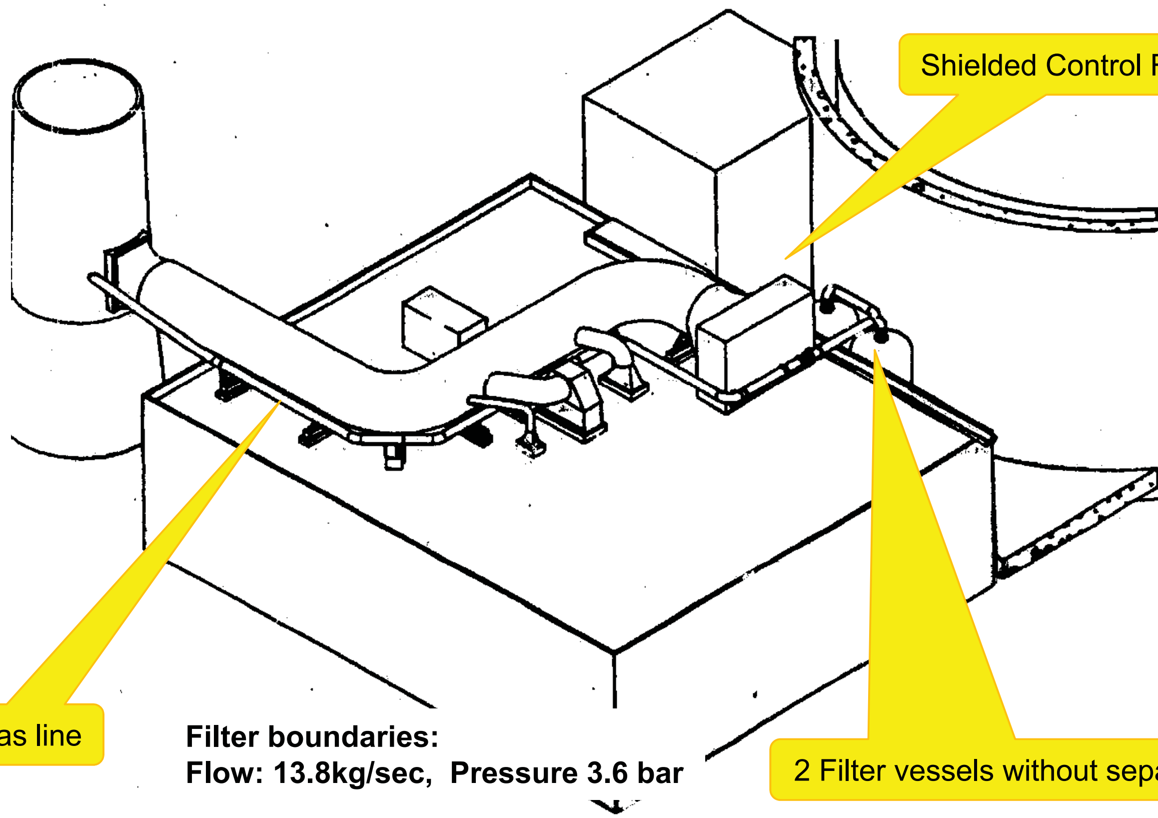
Installed FCVS – Beznau Nuclear Power Plant



Local control room with manual control valves and instrumentation

Installed FCVS – Leibstadt Nuclear Power Plant

Layout for General Electric BWR6

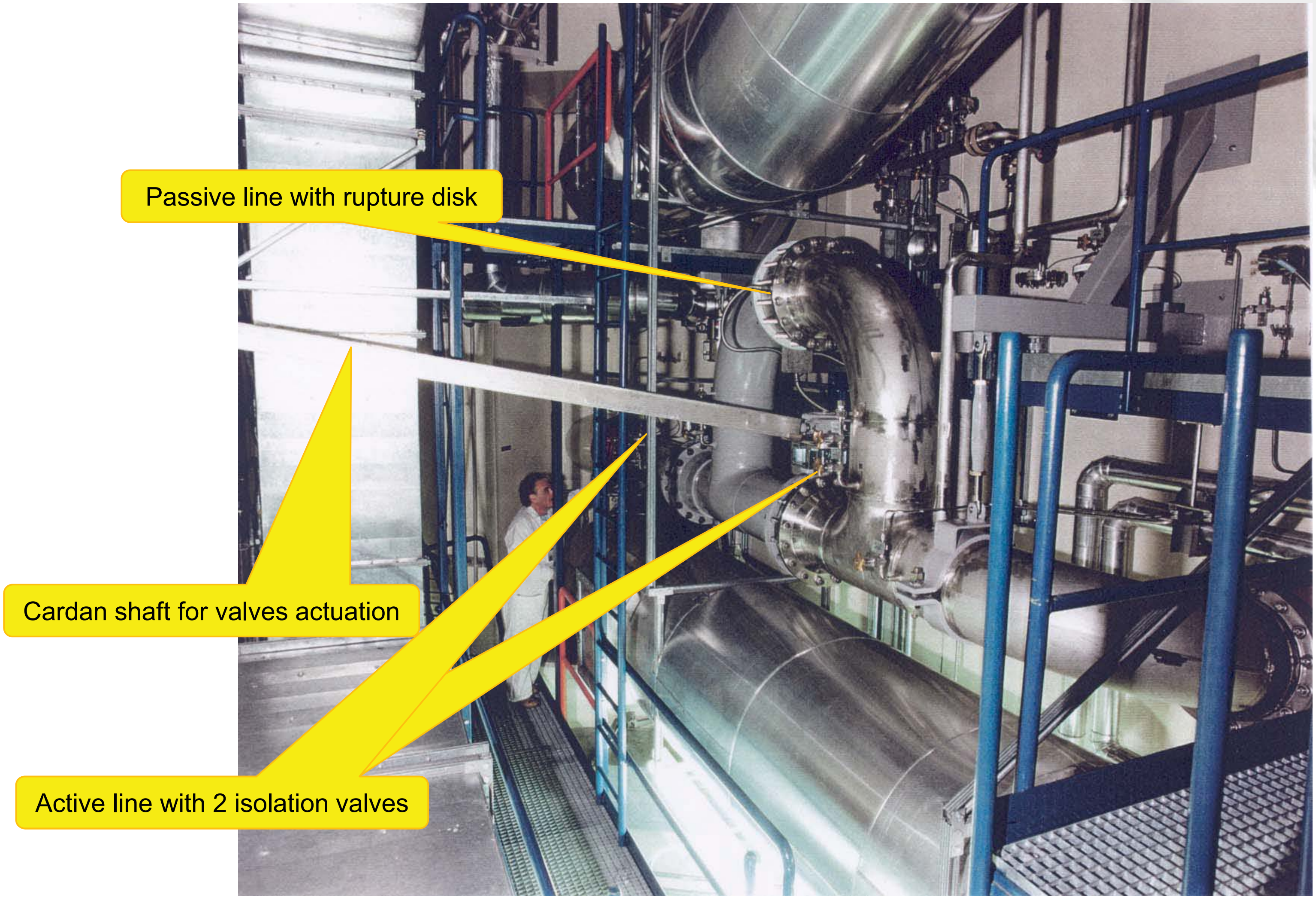


Filter boundaries:
Flow: 13.8kg/sec, Pressure 3.6 bar

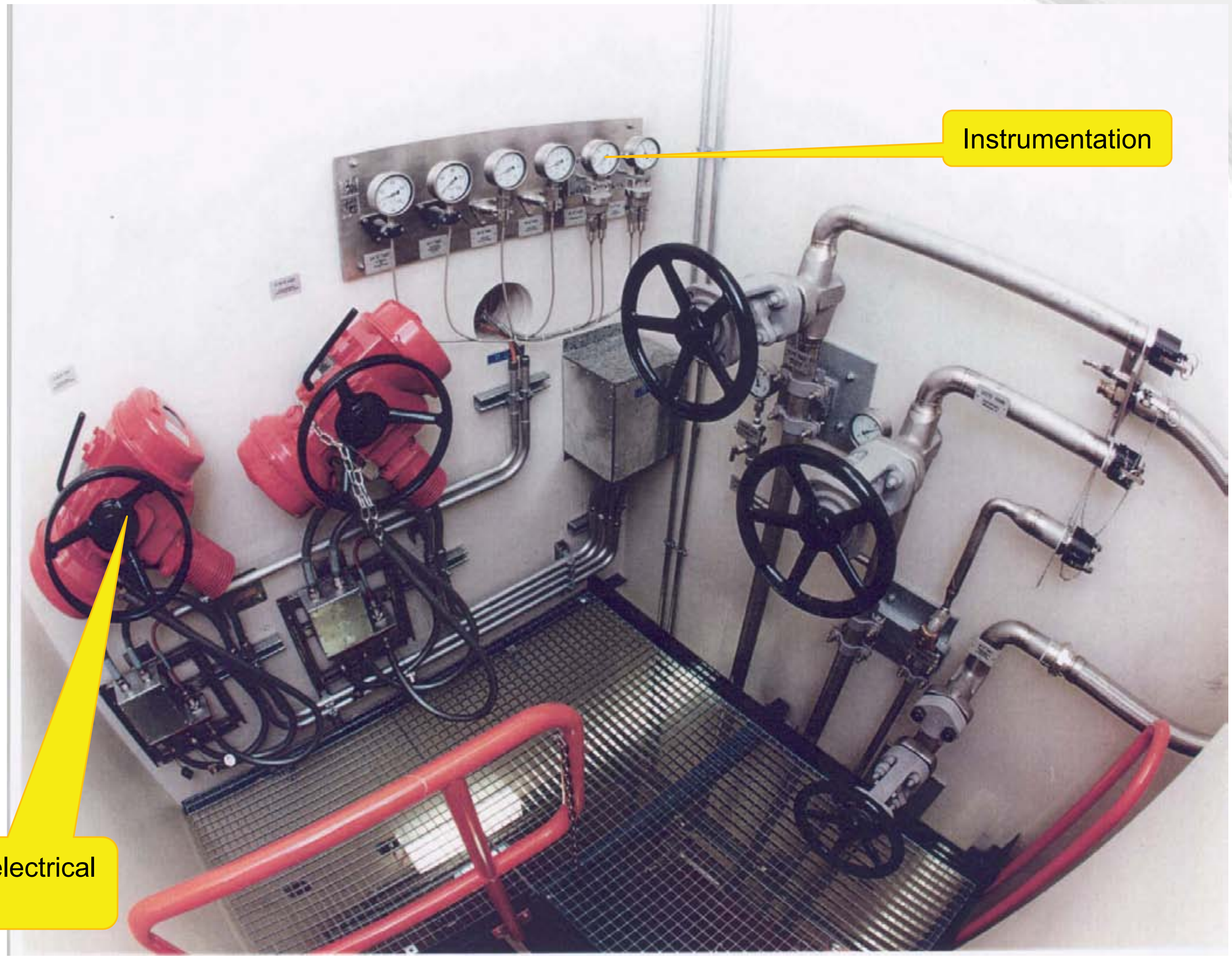
Installed FCVS – Leibstadt Nuclear Power Plant

Delivery of two filter vessels to the NPP Leibstadt

Installed FCVS – Leibstadt Nuclear Power Plant



Installed FCVS – Leibstadt Nuclear Power Plant



Sizing

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➢ Specified by Customer:

- Filtration: Required min. decontamination factors (DF) for aerosols, elementary iodine and organic iodine and boundary conditions accordingly, e.g. flow, gas composition, temp., pressures, cycling, aerosols size and concentration etc. Required Filtration behavior for mid and long term (re-volatilization, re-vaporization, re-suspension)
- Thermodynamics: Max. vent flow rate at given containment pressure, containment volume, gas composition in containment at venting initiation, total decay heat of aerosol and iodine to be scrubbed, steam and non condensable gas generation rates after venting initiation, reactor decay heat evolution at venting initiation and afterwards*
- Fission product: Total aerosol (active/inactive) mass to be scrubbed, total iodine species (metallic, elemental iodine and organic iodide) to be scrubbed, time frame for about the full activity to be scrubbed, acidification potential
- Operation: Time without any operator intervention (autarky), passivity without power, full passivity without power and rupture disk venting opening
- Layout (walkdown mandatory): Control room, filter room, penetration, existing in- and outlet piping

Note: Mandatory for quote

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Sizing

- **Given in CCI test base:** Specific test results (aerosols, iodines) with variation of nozzles sizes, pressure ratios and volumetric flows in the 1 nozzle-full scale test bench:
  - 1.6 to 5 bar (1.5 to about 4 pressure ratio) filter inlet pressure
  - Subcooled to saturated pools, pure steam to non-condensable gas to steam mixture flows
  - Submicron (0.3 μm to 2.5 μm –geometric-) particles, different materials for aerosols
  - Very small to very high iodine concentrations for iodine retention (iodine concentration, absorbed dose)
  - Iodine removal at low (pH 2) to high (pH14) pH and cold to hot water temperature
  - Complementary test data base: Iodine and aerosol pool scrubbing and aerosol removal in water pools with submerged structures, droplet entrainment by bubble burst

Sizing

➢ Calculated by CCI:

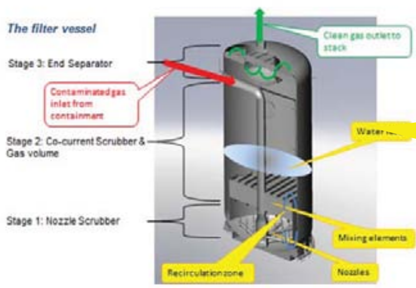
- **Select orifice size and number** to match desired max. vent flow rate and simultaneously check the filter pressure ratio for the lowest flow with regard to decontamination
- Check **Depressurization** behaviour
- **Determine Vessel size**
  - Desired autarky (consider simultaneously: steam condensation, water evaporation, water drainage back to filter)
  - Allocate space for aerosol mass remaining below sparger area (no return of contaminants in the containment necessary)
  - Remain in the experimental data base for iodine retention (Iodine concentration, absorbed dose)
- Filter **hydrogen** concentration calc. and decision on **mitigation**

Sizing

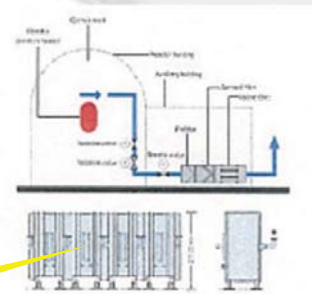
- **Designed by CCI:**
  - P & ID
  - Layout draft including control and filter rooms, piping inlet and outlet lines, penetration
  - Fittings and instrumentation
  - Installation – Operation - Maintenance
  - Shielding
  - ....

Why choosing the IMI filter?

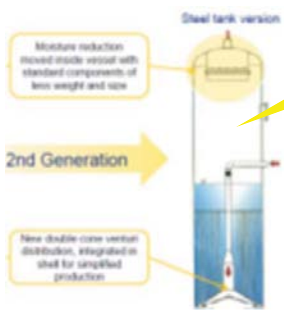
Available filtering technologies:



- Impact Nozzle
- Chemistry
- Mixing elements
- Recirculation zone



- Metal fiber filter
- Molecular sieve



- Venturi Nozzle
- Chemistry
- Metal fiber filter

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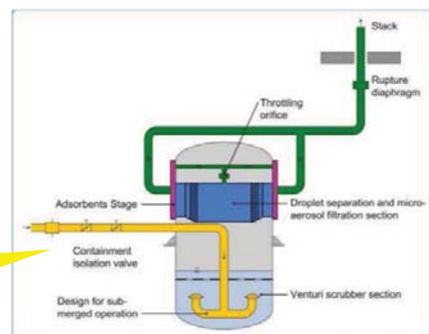
- Molecular sieve



Why choosing the IMI filter? – Critical issues

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Venturi Nozzle:

Sharp **drop in decontamination factors of Venturies** (20!) when out of narrow flow range and filter water level causes large aerosol tansport to metal fiber filtration stage

Narrow volumetric flow range leads to low depressurization rate (long depressurization time) and thus hinders fast operation of low pressure injection pumps

Outlet throttling leads to high vessel pressure = high energy - H2 risk!

Why choosing the IMI filter? – Critical issues

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Metal fiber filter:

High risk of **clogging** with high aerosol load and high temperature

Decay heat of fission products leads to **re-vaporization** of aerosols (hot spots)

Corrosion and high temp. damage to metal fibers

Multiple venting leads to **re-suspension** of deposited fission products

Why choosing the IMI filter? – Critical issues

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Molecular Sieve:

Pre-heating with active N2 gas and pre-conditioning with H2

Poisoning of zeolite through halogens, sulfur compounds, acid fumes and other fission products

High temperature sharply reduces absorption, i.e. by steam absorption and catalytic H2-O2 / silver reaction

High tempearture by Decay heat (including absorbed nobles gases) leads to **Re-vaporization** of aerosols and iodine

Multiple venting leads to **re-entrainment** of fission products

Why choosing the IMI filter? – Summary Critical Issues

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- **Venturi nozzles** have a **narrow flow range decontamination efficiency** an thus allow the **transfer of the filtration function to the next filtration stages (fine mesh stage, molecular sieve)**

- **The Venturi nozzles and Dry filter technologies (fine mesh, molecular sieve) do not allow for fast depressurization rate** (or sudden pressurization) **due to flow limitation**

- **Metal fiber filter have a high clogging risk with uncontrollable** (radioactive) **materials and liquid/solid particules mixtures**

- **Molecular sieve need pre-heating and pre – conditioning.** They are subject to **uncontrollable poisoning**

- **Dry only Filtering technologies solution,** i.e. fine mesh or/and molecular sieve, have to cope with the **the total amount of fission product heat: re-vaporization** and **filter damage** is expected

- **The ACE tests** late eightys are from today's view **not representative for high aerosol load, large flow range** and **irradiation influence** on filtration. The **re-volatilization, re-vaporization** and **re-suspension are not adressed**

Why choosing the IMI filter? – The reasons are:

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- **Highest decontamination factors for aerosols** from high to low flows allows **wide operation flexibility,** e.g. fast depressurization without compromise on filtration

- **Highest decontamination factors for iodines** *by adequate chemistry*

- **Re-volatilization of iodines** – **issue solved** under all possible conditions *by adequate chemistry*

- **Re-vaporization of aerosols and iodines - issue solved,** i.e. *all fission products kept in filter water*. The same reason **excludes Re-entrainment** when multiple venting cycles venting

- **Best laboratory** worldwide ready to answer specific Utilities request **ready to test**

Conclusions

- **IMI - PSI have developed a 2nd generation of Filtered Containment Venting System with a unique, highly efficient filter system**
- **For the first time in the nuclear power industry, a technology to prevent the release of active aerosols AND iodines species to the environment is available**
- **The installed approximately 120 FCVS, mainly in Europe have deficiencies in filtering aerosols and iodines. Other reactors worldwide do not have any filtering capabilities despite the fact that approximately half of the core damages scenarios might require containment venting**
- **Nuclear Safety Athorities and Utilities may consider the installation of a 2nd generation Filtered Containment Venting System to better protect public health and safety and preclude the possibility of land contamination due to the recent events**

Disclaimer

The information presented here is not considered to be a commercial evaluation and or interpretation of performances of the available containment venting filter systems.

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That's all Folks!