Filtered Containment Venting System

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Overview

- The problem: The core damage scenario might require depressurization (venting) of the containment.

- The solution: A first generation of filtered containment venting system (FCVS) has been installed on approximately 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 in the proposed technology.
How does it work?

The filter vessel

Stage 3: End Separator
Contaminated gas inlet from containment

Stage 2: Co-current Scrubber & Gas volume

Stage 1: Nozzle Scrubber

Clean gas outlet to stack
Filtration & separator
Water level
Mixing elements
Recirculation zone
Nozzles
How does it work – Stage 1, Nozzle scrubber

- Mixing elements
- Vessel
- Riser
- Central distribution pipe
- Sparger assemblies
- Distribution system side arms
How does it work – Stage 3, end separator

**Triple deflection**

- **Drain line**
- **Inlet pipe**
### How does it work – Summary

#### 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

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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

- Reactor building
- Containment
  - Rupture disk, only for passive system option
  - Isolation valves
  - Water conditioning - immediate
  - Contaminated gas line (2 lines for BWR)
  - Clean gas line
- Stack
- Water conditioning - long term
- Drain

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
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, SnO2 particles are generated.

Facility to prepare aerosol laden steam-gas mixture flow

A representative module of FCVS filter used for aerosol tests

Iodine species generation and feed system

Iodine species on-line/grab sampling measurement system

No high retention of methyl iodide and I₂ 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 I₂ for all
    other gaseous species)
  - Fix iodide ions to suppress their radiolytic and thermal oxidation

- Over 1000 tests conducted using I₂ and CH₃I covering:
  - Very acidic to strong basic solutions
  - Room to high solution temperature
  - A large range of initial CH₃I 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 $\gamma$-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 $\beta$ irradiations

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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\(_3\)I)** > 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

Pressure ratio across the filter

Decontamination share (qualitative)
Droplet Separator
Impact Nozzle
Mixing Elements & Recirculation

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Permanent sink for iodide ions 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

è Re-volatilization of iodines does not occur
**Experimental data base – Conclusion of the tests (II)**

**Improvements of filtration from 1st to 2nd generation**

<table>
<thead>
<tr>
<th>Accident Phase</th>
<th>Relevant, volatile Nuclids</th>
<th>Spec. Retainment Factor for FCVS Gen. 1</th>
<th>Spec. Retainment Factor for FCVS Gen. 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>conservative</td>
<td>best estimate</td>
<td>conservative</td>
</tr>
<tr>
<td>Phase 1: <strong>short term</strong> retainment capacity after first ventings of scrubber/filter containers</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cs 134/137-aerosols</td>
<td>Min. 1’000</td>
<td>&gt;200’000</td>
<td>Min. 10’000</td>
</tr>
<tr>
<td>I-131 organic</td>
<td>1</td>
<td>&lt;5</td>
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</tr>
<tr>
<td>I-131 elementary</td>
<td>100</td>
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<td>&gt;200’000</td>
<td>Min. 10’000</td>
</tr>
<tr>
<td>Phase 2: <strong>long term</strong> retainment capacity after several ventings of scrubber/filter containers <strong>NEW CONSIDERATION! FROM R&amp;D</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>Cs 134/137 – aerosols</td>
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Installed IMI FCVS

Beznau Nuclear Power Plant – Layout for Westinghouse 2 loops PWR

Stack along reactor building
Separate building

Filter boundaries
Flow 4.3kg/sec, Pressure 4.6 bar

Shielded local control room
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

2 Filter vessels without separate building

Clean gas line

Shielded Control Room
Installed FCVS – Leibstadt Nuclear Power Plant

Delivery of two filter vessels to the NPP Leibstadt
Installed FCVS – Leibstadt Nuclear Power Plant

- Passive line with rupture disk
- Cardan shaft for valves actuation
- Active line with 2 isolation valves
Installed FCVS – Leibstadt Nuclear Power Plant

Manual / electrical actuators

Instrumentation
Sizing

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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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

- Venturi Nozzle
- Chemistry
- Metal fiber filter
- Molecular sieve
Why choosing the IMI filter? – Critical issues

Venturi Nozzle:

Sharp drop in decontamination factors of Venturies (20!) when out of narrow flow range and filter water level causes large aerosol transport 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

Metal fiber filter:

- High risk of clogging with high aerosol load and high temperature
- Corrosion and high temp. damage to metal fibers
- Decay heat of fission products leads to re-vaporization of aerosols (hot spots)
- Multiple venting leads to re-suspension of deposited fission products
Why choosing the IMI filter? – Critical issues

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
- **Multiple venting leads to re-entrainment** of fission products
- **High temperature by Decay heat (including absorbed nobles gases)** leads to **re-vaporization** of aerosols and iodine

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Why choosing the IMI filter? – Summary Critical Issues

- **Venturi nozzles** have a **narrow flow range decontamination efficiency** and 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 particles 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 **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 addressed.
Why choosing the IMI filter? – The reasons are:

- **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 Authorities 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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