Status of FCVS in OECD countries

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Enhancing nuclear safety




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Introduction

- On-going status report on FCVS in OECD framework
- Stress tests after Fukushima led many countries to consider the implementation of FCVS as an improvement of the response to SA
- Some countries consider to improve existing systems (robustness to hazards, safe use and filtration efficiency for prolonged use in SA)
- Recent advances in ST research and filtration tech. to be considered
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Objectives/benefits of (F)CVS as SAMM

- Additional means to protect the containment integrity (maintain the containment function until stable conditions are reached, no matter how severe the accident is)
- Limitation of radioactive releases to the environment
  - Protect on-site workers and population, minimize extent of land contamination
  - Ease on and off-site emergency response
- For some designs (BWR), residual power heat evacuation (also for DBA or design extension conditions (common cause RHRS failures))
- For some designs, reduction of H_2 explosion risk

FCVS Safety Requirements (depending on FCVS objectives and countries)

- More or less prescriptive: FCVS not necessarily explicitly mandated
- The containment shall be protected from overpressure and off-site releases shall be minimized in a SA
- In some cases, unfiltered and uncontrolled releases from the containment to be precluded or if venting is provisioned as SAMM, the system has to be provided with efficient filtration
- In other cases: SA capable venting systems without prescribed filtration (HCVS), notably wet-well venting for some BWRs
- In some cases, prescribed delayed vent timing (e.g., > 1 day)
- In some cases, prescribed vent capacity (decay heat removal, pressure decrease rate), opening and closing pressures

FCVS Safety Requirements (depending on FCVS objectives and countries)

- In some cases, prescribed max. extent of land contamination:
  - frequency of accidents with releases exceeding 10^{14} Bq of ^{137}Cs to be < 5 10^{-7} - 10^{-6}
  - or releases to be < 0,1% of ^{134}Cs and ^{137}Cs core inventory
  - or contamination to be limited to a few tens of km^2
- In some cases, compatibility with protection measures for the population prescribed (in conjunction with delayed venting)
- In some cases, compatibility with plant workers exposure limits prescribed
- In some cases, FCVS Decontamination Factors (DFs) prescribed: usually set to > 1,000 for radioactive aerosols, > 100 for molecular iodine
- In some cases, resistance to hydrogen loads and hazards considered

Venting Strategies and Procedures

- Timing (critical): dependent on reactor type and design, on accident progression, on venting objectives, decision guided by SAMG and taken by competent authorities
  - As little as a few hours for some small containments (some BWRs)
  - Usually, a day or more for larger containments (some BWRs, PWRs, PHWRs)
- Pressure: venting opening and closing pressures based on containment design pressure and assessed margins to containment failure
- Opening/cycling: multiple or long venting considered as long as no other cooling system is recovered
- Passive or active actuation: line to be closable, to be opened and closed easily and surely
- Operation: guided by controls and instrumentation

- Fast accident progression
- Sudden pressure increase (HP RPV failure, energetic events)
- Early venting as SAMM

1 day

- Wait for more favorable conditions (in and out containment)
- Coordinate with on and off-site emergency response

Pressure approaching containment failure limits

Guide for Main FCVS Design Requirements

- Reliable containment decay heat transfer and pressure decrease (for SA TH conditions, possibly incl. energetic events)
- Pipes, supports, valves designed for safe and reliable operation for considered dynamic loads
- Sufficient aerosols (up to several 100 kg), gaseous iodine (up to tens of g) and heat load (up to hundreds of kW) capacities (vent timing and duration critical)
- Autonomy time: e.g. 24 h for liquid filters (provisions to be made for 72h)
- Control of aerosols/iodine re-vaporisation/re-volatilisation for long term use
- System maintenance (liquid systems) and operation to be done safely in SA
- Safe distance to H_2 combustion limits or designed to withstand combustion loads
- Robustness to hazards

Filtration efficiency (guide for target values)

Decontamination factors

- > 1,000 for radioactive aerosols incl. small size and hygroscopic aerosols (10,000 may be desirable for venting with high loads or to further reduce long-term land contamination)
- > 100 for molecular iodine
- > 10 for organic iodides
- Gaseous ruthenium and noble gases filtration issue to be assessed more thoroughly

Filtration technologies

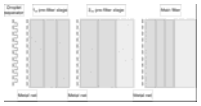
- Existing technologies allow reaching such DFs for aerosols and molecular iodine under conditions obtained from SA calculations
- Some qualification exists for such SA conditions (ACE tests, designers tests)
- Less knowledge exists for organic iodides retention
- Filtration efficiencies for more “challenging” conditions (high loads, long term operation, energetic events) need to be further assessed (re-volatilisation , re-vaporisation)

Existing filtration technologies/implementation

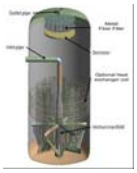
- Solid filtration: metal fiber filter, deep bed filter, sand bed filter (coupled with MFF)
- Liquid filtration: chemically doped pool scrubber for gaseous iodine retention and heat sink, usually coupled with a droplet separator and deep bed fine aerosol filter
- Pre-filtration in some cases (e.g. wet-well scrubbing, pre-filters inside or outside containment), in-containment filtration limits radioactivity transfer and on-site workers exposure
- Some flexibility in implementation (depending on systems): inside or outside the containment (or partly), possibility to add filtration stages (e.g. zeolites)

Technologies/implementation

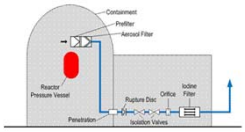
MFF



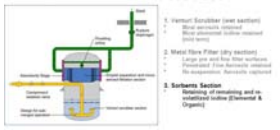
Scrubbers



Example of implementation



FCVS PLUS



Source term (ST) evaluations for FCVS

- ST evaluations factored into accident analysis in different countries: importance for FCVS regulatory assessment and for design and operation requirements for FCVS
- Besides aerosols, specific attention to be given to RI, IOx particles as they may contribute significantly to the ST in some accidents; possible contribution of Ru oxides to the ST under investigation
- No technology exists for efficient filtration of noble gases and the benefit of reducing their releases would have to be balanced with the activity accumulation on a specifically designed system
- Knowledge-base for "delayed" in-containment ST (re-volatilization/re-suspension from surfaces and pools) will be extended through on-going R&D programs
- Deterministic consequence analyses show large reduction of radiological impact and costs (~ /10) when comparing effective filtered releases against unfiltered releases
- In the US, these benefits are offset by the low probability associated to accidents where the FCV option would be useful

Assessed risks, potential improvements for FCVS

- Venting operation strategy:
  - Develop "detailed" assessment of containment behavior under SA conditions (incl. energetic events)
  - Develop "robust" in and out-containment instrumentation to guide optimized FCVS use
  - Redundancy and protection of opening and closure systems
- Limitation of H_2 combustion risks: hardened heating or inerting, isolated stack to chimney exhaust, design to withstand combustion loads
- External filter loading reduction by pre-filtration in the containment
- Filtration efficiency for "challenging" conditions
- Limit FCVS shared between two or more units
- Design systems to be "robust" to hazards (seism)

Concluding remarks

- All countries recognize the potential benefits of FCVS (for emergency response, reduction of extent of land contamination and health effects and increase of social acceptability) but FCVS should be considered in interconnection with other SAM strategies (no benefit for bypass accidents)
- FCVS implemented before Fukushima were mainly destined to manage long-term pressure build-up in the containment, new FCVS may be designed with perhaps more challenging conditions (management of early phases of the accident, cycling or long term use under severe conditions) - robustness, safe use and reliability of FCVS for such conditions to be further assessed
- Importance of reference ST evaluations
- Specific attention to be given to RI and IOx, to "delayed" contributions to ST
- Different approaches used for costs/benefits assessments

Annexe

Country	NPPs	no FCVS	HGSPV	Metal + sand bed	DPM	FILTRA-MVSS	SULZER CCI	EFADS	Comments
Belgium	7 PWR	□							Planned in 5 units which will operate beyond 2015 (no design selected yet)
Canada	19 PHWR Single unit (1) Multi units (18)		•		○			•	HGSPV for Point Lepreau single unit, DPM planned in 4 Darlington units 4 EFADS shared among 18 reactor units, EFADS are designed for SMA
Czech Republic	4 VVER-440 2 VVER-1000	■							Under assessment in conjunction with IAMM for corium cooling (in or ex-vessel)
France	58 PWR			•					metal pre-filter inside containment, sand bed filter outside containment
Germany	7 PWR		•		•				DPM in 3 PWR units
	2 BWR		•						
South Korea	19 PWR	□							Only Wolsong-1 Unit equipped with HGSPV Other units are planned to be equipped with FCVS by 2015 or later, development of a Korean system under consideration
	4 PHWR	□	•						
Spain	6 PWR	□							PWR: FCVS implementation is planned by 2016 BWR: Hardened venting available. Filter implementation is planned in 2017
	1 BWR	□							
Sweden	3 PWR					•			
	7 BWR					•			
Switzerland	3 PWR		•				•		HGSPV type at Gösgen F-MVSS type at Mühleberg
	2 BWR					•	•		
USA	69 PWR	■							Preparation of guidance documents on Hardened CVS for BWR Mark I & II. Implementation by 2018 or earlier.
	35 BWR	■							
Bulgaria	2 VVER-1000		•						
	2 VVER-440	■							
Finland	2 BWR		•						FCVS is not feasible in VVER-440 due to the steel shell of containment that is vulnerable to sub-stmospheric pressures EPR plant under construction will be equipped with FCVS
Japan	24 PWR	□	○		○				HGSPV and DPM planned for some PWRs HGSPV planned for some BWRs, development of a TEPCO system considered
	26 BWR	□	○						
Romania	2 PHWR		○						HGSPV planned
Slovenia	1 PWR				•				DPM installed in 2012
Netherlands	1 PWR		•						

■ no FCVS □ planned but design not yet selected ● installed ○ planned