International Trip Report

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2. Subject:

The purpose of the international activity is to obtain and exchange information with countries having experience with facilities that have installed filtered containment venting systems (HFCVS). This activity is of special relevance to the NRC as the staff considers potential regulatory actions in response to SRM-SECY-0137, dated December 15, 2011, and Near Term Task Force Recommendation 5. Information relating to the function, design and performance requirements of HFCVS, as well as understanding the practicality installing filters, is an important element of the staff's analysis and decision-making on whether or not filtered vents should be required at facilities in the U.S. In SRM-SECY-0137, the Commission directed the staff to provide a "fully developed justification" for all proposed requirements that involve a redefining the level of protection of public health and safety that should be required as adequate in accordance with the backfit rule. This proposed activity is a part of the process to gather the necessary technical information prior to making recommendations.

3. Dates of Travel and Countries/Organizations Visited:

04/17/2012 - 04/26/2012

4/18 Forsmark NPP, Sweden;
4/19 Swedish Radiation Safety Authority (SSM), Stockholm, Sweden;
4/20 Ringhals NPP, Sweden;
4/24 Leibstadt NPP, Switzerland;
4/25 Muehleberg NPP, Switzerland

4. Desired Outcome:

Obtain relevant information relating to HFCVS already installed at facilities: (1) regulatory basis, (2) functional performance requirements, (3) design requirements; (4) quality standards, (5) constructability, (6) operating procedures, and (7) cost (construction and operations). When compared with information relating to the current status of U.S. facilities, the staff will have a better understanding of whether or not HFCVSs will provide sufficient improvements to overall safety. Information will also be gathered to assist the NRC staff in developing interim staff guidance relating to hardened venting systems required by orders to BWR facilities. The staff guidance is to be issued by August 31, 2012.

5. Results Achieved:

The international trip exceeded expectations. Participating members of the NRC staff obtained valuable information directly from the engineers who designed, installed, tested, and maintain FCVSs at their respective nuclear power installations. The trip findings will support JLD/NRR and RES efforts to provide analysis and recommendations regarding the need, cost and benefit associated with enhanced filtered venting capability. The trip was beneficial because a number of detailed facets related to FCVSs were investigated in far greater detail than would otherwise have been feasible including:

- Walk-down inspections of existing filtered vent designs, including accessible locations within radiological controlled areas, at four operating BWR nuclear plants
- Discussions of operational considerations associated with the systems, especially remote and back-up operations, with plant operators (Vattenfall in Sweden; KKL and BKW in Switzerland)
- Maintenance and testing activities required to maintain system performance
- Design requirements, such as seismic capability, necessary for reliable operation in the spectrum of potential severe accidents
- Additional mitigating strategies and systems which have been installed to complement the FCVS, such as the capability to that water is present below the reactor vessel in the event of lower reactor vessel head failure

6. Summary of Trip:

A summary of the NRC staff's itinerary included the following activities:

Sweden (April 17-20)

- Engaged in bilateral discussions on the regulatory basis for filtered containment venting systems (FCVS), and other mitigating systems and strategies that are required in Sweden to protect the containment, with representatives from the Swedish Radiation Safety Authority (SSM).
- Discussed the design, installation and maintenance aspects of FCVS at the Forsmark and Ringhals nuclear power plant sites with the owner/operator, Vattenfall. Also discussed the implementation of other regulatory requirements relating to FCVS and related plant systems with Vattenfall representatives, and
- Toured the FCVS facilities at two operating BWR nuclear plants, Forsmark Unit 2 and Ringhals Unit 1

In Sweden, the team was accompanied by Mr. Leif Karlsson, head of the Nuclear Power Plant Safety/Operations organization at SSM.

Switzerland (April 23-26)

- Engaged in bilateral discussions on the regulatory basis for filtered containment venting systems (FCVS), and other mitigating systems and strategies that are required in Switzerland to protect the containment, with representative from the Swiss nuclear regulatory authority, ENSI-HSK

- Discussed the design, installation and maintenance aspects of FCVS at the Leibstadt and Mühleburg nuclear power plant sites with the owner/operators, KKL and BKW, and ENSI(formerly HSK) resident inspectors
- Toured the FCVS facilities at two operating BWR nuclear plants, Leibstadt and Mühleberg

General Findings Applicable to Sweden and Switzerland

- Mitigation capability for severe accidents is a legal and regulatory requirement.
- Sweden and Switzerland took steps to strengthen containment as a matter of preserving defense in depth in the event of a severe accident
- Both countries implemented a holistic approach to preserving the containment function by requiring FCVS as well as redundant and diverse methods of providing water to protect the containment liner under the reactor vessel.
- Representatives from the owners/operators uniformly expressed an overall satisfaction with the FCVS. The owners/operators did not identify any technical difficulties relating to the installation and maintenance of their respective FCVS systems.
- The construction and installation of the FVCSs did not significantly impact normal operations or extend scheduled refueling outage times.
- Construction was generally completed within 2 to 3 years.

Insights from Sweden

The NRC staff met with senior representatives from the Swedish Radiation Safety Authority (SSM) on Thursday, April 19 at SSM Headquarters in Stockholm, Sweden, to discuss the regulatory basis and design specifications for FCVSs in Sweden. Representatives from SSM included:

- Leif Karlsson, Operations Head
- Anne Edland, Head, Man-Technology
- Lars Skanberg, Head, Reactor Technology and Structural Integrity
- Robert Finck, Emergency Preparedness and Response
- Lars Gunsell, System Assessment
- Anders Hallman, Senior Analyst
- Gustaf Lowenhielm, Senior Advisor
- Wiktor Frid, Analyst, Thermal Hydraulics and Severe Accidents

Regulatory Basis for FVCS

A number of initiatives in the early 1980s paved the way for the ultimate decision to install FCVS at Swedish nuclear power plants. Following the accident at Three Mile Island (TMI) in 1979, the government established a committee to look into the lessons learned from the TMI accident, and to recommend ways to improve safety. The committee published its findings in the “Report by the Swedish Government Committee on Nuclear Reactor Safety" in December 1979. Among the various initiatives outlined in the report, the committee recommended that existing Swedish nuclear plants be able to (1) mitigate the consequences of a severe accident by strengthening containment, and (2) reduce risks that could result in radiation fatalities or high radiation dose from ground contamination. An important consideration of the committee was that, in cases where the containment barrier was threatened by pressure build-up; the controlled release of limited amounts of activity was preferable to a possible catastrophic failure of the containment barrier with a large and uncontrolled release as a result. In addition potential damage to structures and systems in the plant could occur as result of a catastrophic failure.

The Swedish Parliament later established general guidelines for the country's reactor safety program as part of its 1980/81 Energy Bill that was passed in May 1981. These guidelines were also reconfirmed in Sweden's 1984/85 Energy Bill, as well as in official statements made by the government following an evaluation of the Chernobyl accident. According to the 1981 guidelines, the main priority for Swedish nuclear power plants is to prevent core damage. Consequently, feedback from operating experience and plant-specific probabilistic safety analyses (PSAs) become important components of Sweden's reactor safety program. Sweden's reactor safety program also clearly states that, despite measures taken to prevent core damage, accidents involving severe core damage may nevertheless occur, and that measures should be taken to ensure that releases from severe accidents are kept low.

Therefore, in order to take measures to strengthen containments and reduce the risks to Swedish citizens from high radiation doses from ground contamination, the 1980/81 Energy Bill also required the owners and operators of the Barseback nuclear power plant, which is located approximately 20 km from the Copenhagen, Denmark, to expedite the installation of a FCVS at the facility. Sweden later followed this action up by issuing a "regulatory decree" (order) in October 1981 further requiring that the FCVS for Barseback be operational no later than 1985, and that completion of the project be a condition of its operating license. The regulatory decree also established performance requirements for the new filtering system by requiring that 99.9% of radioactive isotopes, excluding noble gases, should be retained in either the containment or the new filter when venting during a severe accident. The Barseback licensee was further required to study and identify any adverse interactions that might exist with the installation of the FCVS. During a bilateral meeting between the Swedish Radiation Safety Authority (SSM) and members of the NRC staff in April 2012, SSM representatives emphasized that the agency considered it "unacceptable" for their country to require the evacuation of Copenhagen in the event of an accident at Barseback.

The 1980/81 Energy Bill also required licensees to consider the installation of FCVSs at Sweden's remaining operating nuclear plants located at Forsmark, Ringhals and Oskarshamn. The bill further instructed the owners/operators to identify and consider alternative solutions to FCVS, where feasible. Swedish authorities later determined during the process that cost/benefit considerations would not be the deciding factor in whether or not to ultimately require FCVS at Forsmark, Ringhals and Oskarshamn.

As a result of the 1980/81 Energy Bill, Sweden constructed a one-of-a-kind FCVS for the Barseback nuclear plant. The Barseback FCVS consisted of an extremely large cylindrical building that contained gravel as the primary medium to trap radioactive particles that would be released during venting operations. The size of the filter structure rivaled the size of the containment building itself. The unusual design for the Barseback FCVS was largely due to time constraints outlined in the bill as well as the lack of actual experience and research available at that time on alternate filter designs.

Following passage of the 1980/81 Energy Bill, the Swedish government also established a joint regulator/industry research project, known as FILTRA, to consider other available means to accomplish the objective of strengthening containments. This initiative focused on limiting the release of radioactive material following a severe accident in order to minimize potential dose to the public and mitigate the negative effects of land contamination. According to a March 1981 status report, the strategy was to be based on the concept of reducing risk of release…"that can cause long term ground contamination assuming a severe accident has occurred." The new mitigation systems were to:

- Be fully independent from existing safety systems
- Function passively for the first 24 hours in order to give time to implement preplanned active measures and mitigating strategies
- Ensure limited radioactive release commensurate with existing technical specifications containment leakage rates
- Defend against the risk of over-pressurization sequences that would otherwise rupture containment

As a result of the FILTRA research program, Sweden identified a number of measures that could be taken to protect containment integrity during severe accidents. These measures focused on vulnerabilities uncovered by risk analyses related to containment overpressure failure and containment liner/concrete failure from core debris scenarios. Among these measures included:

- Containment over-pressure suppression
- Lower drywell flooding to protect the basement
- Independent containment spray and water fill systems
- Filtered containment venting systems (FCVS)
- Containment instrumentation for severe accidents
- Containment penetration shielding

In February 1986 the Swedish government decided that the following basic guidelines and criteria shall apply to severe accident management and release mitigation measures at its nuclear power plants:

- There shall be no early fatalities resulting from radiation injuries.
- Ground contamination that would make it impossible to use large areas for long periods of time shall be prevented.
- Events with extremely low probabilities such as major reactor vessel ruptures need not to be considered.
- The same basic requirements with regard to the maximum radioactive release are to apply to all reactors, regardless of location or power output.

The Government also set the following objectives and conditions with regard to accident management and containment venting to be satisfied by the end of 1988 [in part]:

> To protect the containment against overpressure damage in the event of a severe accident and to improve the possibilities of reaching a stable final state after a core accident, it must be possible to carry out controlled containment pressure relief. The relief systems must be designed so that they are activated independently of operator intervention and independently of the functioning of other safety systems if the containment design pressure is exceeded to such an extent that there is risk of unacceptable leakage or risk of damage to the containment. It must also be possible for operating personnel to actively use

these relief systems to reach a safer, more stable state during an accident. Moreover, these relief systems must be designed so that, together with other measures taken to protect the containment, they will be able to make certain that the release to the environment does not exceed the guidelines established by the government.

The new 1986 requirements from the Swedish government are considered fulfilled if the release is less than 0.1% of the core inventory of the Cs-134 and Cs-137 contained in a reactor core of 1,800 MWth, assuming that other nuclides of significance in regard of land contamination are released to lesser or, at most, equal extent. The new limit is well below 200 terabecquerel (TBq).

Severe accident consequence mitigating measures implemented in 1988 at all Swedish NPPs

- Containment filtered venting (BWRs and PWRs)
- Containment overpressure protection (only BWRs)
- Lower drywell flooding from wetwell (only in BWRs with internal recirculation pumps),
- Independent containment spray and containment water filling from external source
- Containment instrumentation for SA (activity, temp., pressure, water level, hydrogen content)
- Containment penetration shielding in lower drywell
- Emergency Operating Procedures for SA

Coping time (time for consideration) for severe accidents

- Manual measures (actions) should not be needed for the first 8 hours,
- Manual measures (actions) that may be needed after 8 hours should be well prepared and controlled by procedures,
- Other measures, which are not prepared, should not be needed until after 24 hours.

The final design requirements for the FCVSs employed on Swedish plants conforms to the following specifications and were, in essence, based on the need to preclude (in their words) the “cliff-edge” effects resulting from uncertainties associated with conventional deterministic and risk analyses:

- A new drywell penetration was required to accommodate the slow over-pressurization severe accident event taking into consideration flooding of the wetwell airspace by the capability provided by an additional independent containment spray system which was also added to insure a reliable means to flood the region under the reactor pedestal
- Separate unfiltered vent system for passive, early overpressure mitigation prior to core damage (closed automatically 10 minutes following opening)
- No acute fatalities allowed
- Very limited area (< 50 km^2 offsite) for potential first year dose resulting from ground contamination (with rain) of greater than 50 mSv. Swedish authorities stated that this is considered met if the release is no more than 0.1% core inventory Cs-134, Cs-137, and Iodine using as a standard an 1,800 MWth-size reactor. The limit is well below 200 terabecquerel (TBq; note: 1 TBq = 10^{12} Bq.) and according to SSM representatives closer to 100 TBq. As a matter of reference, the release from the Fukushima accident is estimated to be approximately 160,000 TBq.
- Required decontamination factor of 100 (actual in-plant tests greatly exceed that value)

- Manual measures (actions) should not be needed for the first 8 hours,
- Manual measures (actions) that may be needed after 8 hours should be well prepared and controlled by procedures,
- Other measures, which are not prepared, should not be needed until after 24 hours.
- Heat removal capability 1% of thermal power
- Nitrogen inerted to handle hydrogen
- Seismic design to the same or greater standard as the primary containment.
- Single train operation
- Valves operable from control room and remotely with both electrical and pneumatic power supplies
- Instrumentation supplied with independent battery back-up power supplies

More current regulations (SSMFS 2008:17) concerning the design and construction of nuclear power reactors were first issued 2004, and are intended on providing more explicit requirements instead of more generalized guidelines for the industry. The new regulations include:

- Additional requirements needed for modernization of nuclear facilities
- A definition of "highly improbable events." These are events which are not expected to occur. However, if the event should nevertheless occur, it can result in major core damage. These events are the basis of the nuclear power reactor's mitigating systems for severe accidents.
- Chapter 5 of SSMFS 2008:17 states that the "reactor containment shall be designed taking into account phenomena and loads that can occur in connection with events in the event class highly improbable events, to the extent needed in order to limit the release of radioactive substances to the environment." To meet the requirement in Chapter 5, a safety evaluation is to be performed for events and phenomena that may be of importance for containment integrity following "highly improbable events."

The present regulatory framework for FCVS was also guided by a study completed approximately 12 years ago regarding the impacts of cleanup efforts relating land contaminated following the Chernobyl accident. Based on the actual costs for cleaning up contaminated areas, contamination and dose rates following cleanup, and the impacts on people, SSM officials quoted members of the Swedish Parliament stating that, in the end, FCVS "are worth it."

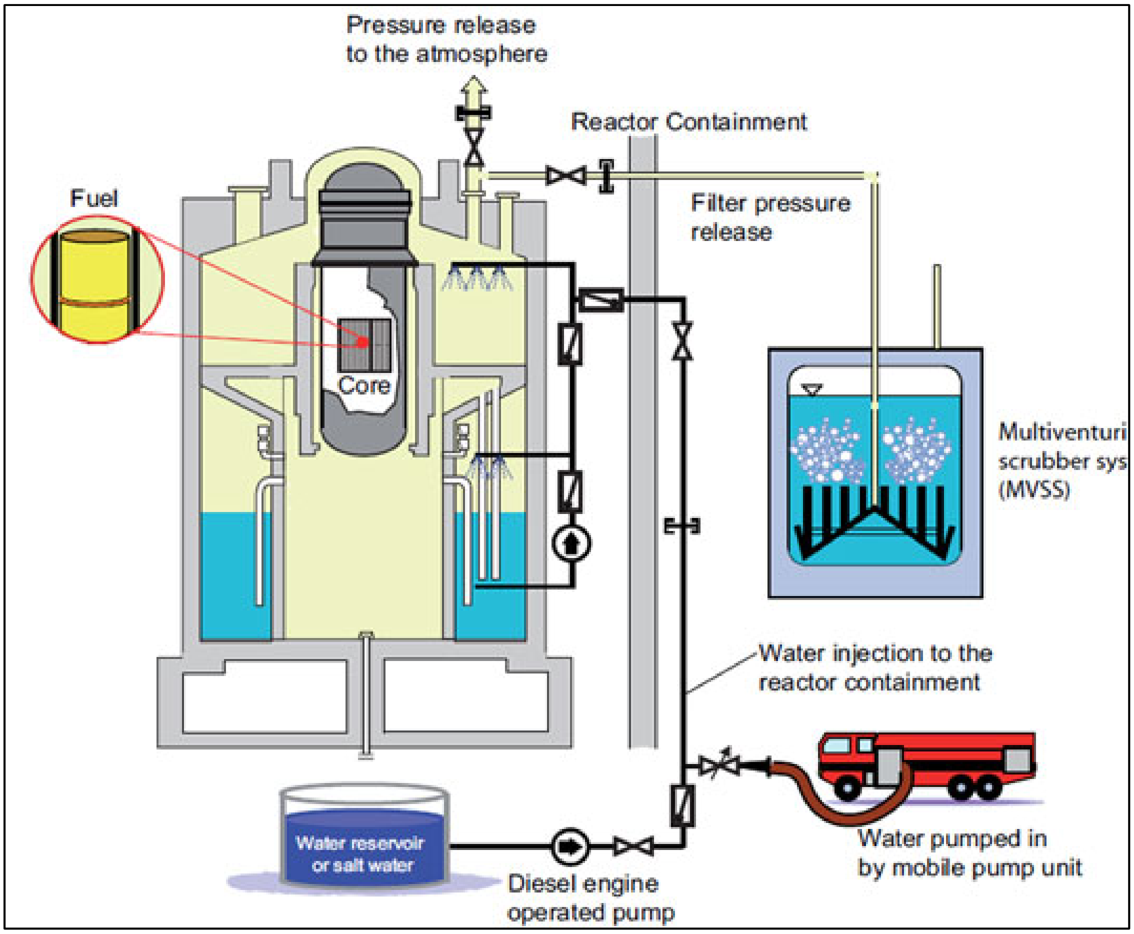


Figure 1 - Severe Accident Mitigation Systems for Swedish BWRs

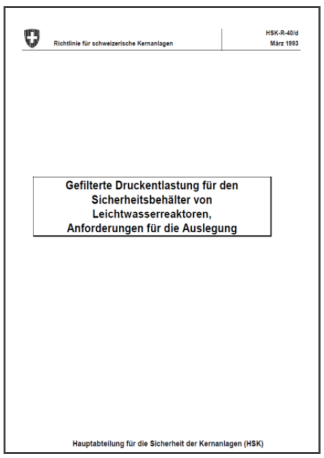
Operational Findings from Forsmark and Ringhals

- A major objective of the design and installation of the FCVS at both Forsmark and Ringhals was that the installation should not impact operations and result in an increase to the planned refueling outage. As a result, the owners reduced plant unavailability time by designing and constructing a separate building adjacent to the reactor building to hold the filter and other support systems. The FCVS was kept separate from other systems in order to eliminate any unintended consequences as a result of modifying existing systems to meet the needs. This also simplified the design and simplified construction that also minimized refueling outage down time.
- FCVS is included in each plant's technical specifications. The allowed outage times (AOTs) are 30 days.
- Installation costs (1988) are estimated at $12.5 million per unit at Forsmark and approximately $9 million per unit at Ringhals
- Annual maintenance, testing, inspection costs were estimated at $10,000-$30,000

Insights from Switzerland

Regulatory Basis for FVCS

The Swiss Nuclear Energy Act requires licensees to backfit, as appropriate, in response to operating experience and consistent with available technology, to further reduce risk to people and the environment. Following TMI, Swiss plants were required to install severe accident mitigation systems (e.g., SUSAN at Mühleberg). Then, in response to Chernobyl (1986) HSK directed licensees to evaluate the FCVS. The goal was to prevent an uncontrolled radioactive release due to loss of integrity of the containment during a severe accident. Ultimately, HSK employed a defense-in-depth argument, and decided to require the installation of FCVSs at all Swiss plants.


Richtlinie für schweizerische Kernanlagen

HSK-R-40/d
März 1993

Gefilterte Druckentlastung für den Sicherheitsbehälter von Leichtwasserreaktoren, Anforderungen für die Auslegung

Hauptabteilung für die Sicherheit der Kernanlagen (HSK)

Guidance was drafted by 1988 with final guidance contained in HSK R-40; installation was completed during the 1989-1993 timeframe. The final guidance directed that the designs possess:

- Heat removal capacity - 1% thermal power
- Passively actuate via rupture disc so as not to require intervention for 24 hours
- Allow operation from the control room and separate remote panel
- Contain their own dedicated power for instrumentation and valve operation
- Seismic Class 1
- High decontamination factors (based on available technology)

Operational Findings from Switzerland

Leibstadt NPP

Function of the FCVS

- Protection of the Primary Containment (PC) against over pressure failure in terms of beyond design accidents with slow pressure increase
- Prevention of uncontrolled release of radioactive material (retention of the major part of active particles and iodine)
- Release the Containment atmosphere via filter (wet scrubbing) over the vent stack

Design Requirements of FCVS

- Valves can be operated remotely from the MCR or manually from the local control room
- Relevant information for system monitoring and operation of the system is displayed in the MCR and the local control room
- Even with the water boiling in the wet scrubber it is possible to operate the system for at least 24 hours without refilling
- Direct irradiation from the filter tanks (when in use) of the people living in the surrounding environment is shielded through the buildings around the FCVS; including the “Sky Shine” the dose rates outside of the plant site are within the dose limits

- Radiological contaminated scrubbing solution can be transferred back into the Containment via the force of gravity
- Refilling and feeding of the system will be done from the local control room, preferably with de-ionized water, if not available with fire water

<u>Mühleburg NPP</u>

PSA Insights

The requirement for installing a filtered containment venting system preceded the PSA at KKM. A feasibility study to install a modified version of the FILTRAMVSS (multi-venturi scrubber system) was performed in the winter of 1988/1989. CDS was installed and placed in service at KKM in 1992. The first KKM PSA was not completed until 1990 (MUSA-90). Therefore, the PSA was not a significant factor in the decision to install the system. However, analysis performed to support updates to the PSA in 2000 and in 2005, contributed to the operating guidelines (actuation and operating procedures) for the system. The design criteria for the MVSS installed at KKM included target values for the filtration efficiency of the system, but did not include probabilistic metrics from the PSA.

FCVS Design Requirements

- Nominal relief capacity: steam production corresponds to 0.8% of the thermal power
- Maximum relief capacity: steam production corresponds to 1% of the thermal power
- Retention factor for aerosols: ≥ 1000 (99.9%)
- Prevention of long-term contamination by Cs
- Retention factor for iodine: ≥ 100 (99%)
- Seismic class 1 (highest requirement)
- Efficient at varying pressures and flow rates
- Max. dose for personnel 0.1 Sv
- System availability during station blackout
- 100 hours independent operation of instrumentation
- Passive depressurization (rupture disc)

Estimated installation costs of FVCS:

- Leibstadt - $11 million in 1993
- Mühleberg - $6 million in 1990 excludes filter vessel (due to unique reactor building design)

Other

- Maintenance costs estimated at $50,000 to $100,000/year
- Enhanced water chemistry is planned to improve iodine retention
- FCVS is in the Technical Specifications with a 10-Day AOT

Additional Information/Discussion: N/A

Pending Actions/Planned Next Steps for NRC:

The NRC staff is evaluating information relating to the topic of filtration of containment vents, and is preparing a Commission Paper as directed by SRM-SECY-11-0137. The paper is currently scheduled for completion in November 2012.

Points for Commission Consideration/Interest:

The NRC staff has had the opportunity to brief all the Commissioners on the lessons learned from the staff's trip to Sweden and Switzerland. The staff will be presenting the results of its review on filtered containment venting in an upcoming Commission Paper.

"On the Margins": N/A

Attachments: None