Unclassified **NEA/CSNI/R(2002)6**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development **03-Oct-2002**

English text only

NUCLEAR ENERGY AGENCY
COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

NEA/CSNI/R(2002)6
Unclassified

Knowledge Base for Strainer Clogging - Modifications performed in different countries since 1992

FINAL REPORT

JT00132551

Document complet disponible sur OLIS dans son format d'origine
Complete document available on OLIS in its original format

English text only

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996), Korea (12th December 1996) and the Slovak Republic (14 December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full Member. NEA membership today consists of 28 OECD Member countries: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

COMMITTEE ON THE SAFETY OF NUCLEAR INSTALLATIONS

The Committee on the Safety of Nuclear Installations (CSNI) of the OECD Nuclear Energy Agency (NEA) is an international committee made up of senior scientists and engineers. It was set up in 1973 to develop, and co-ordinate the activities of the Nuclear Energy Agency concerning the technical aspects of the design, construction and operation of nuclear installations insofar as they affect the safety of such installations. The Committee's purpose is to foster international co-operation in nuclear safety among the OECD Member countries.

The CSNI constitutes a forum for the exchange of technical information and for collaboration between organisations, which can contribute, from their respective backgrounds in research, development, engineering or regulation, to these activities and to the definition of the programme of work. It also reviews the state of knowledge on selected topics on nuclear safety technology and safety assessment, including operating experience. It initiates and conducts programmes identified by these reviews and assessments in order to overcome discrepancies, develop improvements and reach international consensus on technical issues of common interest. It promotes the co-ordination of work in different Member countries including the establishment of co-operative research projects and assists in the feedback of the results to participating organisations. Full use is also made of traditional methods of co-operation, such as information exchanges, establishment of working groups, and organisation of conferences and specialist meetings.

The greater part of the CSNI's current programme is concerned with the technology of water reactors. The principal areas covered are operating experience and the human factor, reactor coolant system behaviour, various aspects of reactor component integrity, the phenomenology of radioactive releases in reactor accidents and their confinement, containment performance, risk assessment, and severe accidents. The Committee also studies the safety of the nuclear fuel cycle, conducts periodic surveys of the reactor safety research programmes and operates an international mechanism for exchanging reports on safety related nuclear power plant accidents.

In implementing its programme, the CSNI establishes co-operative mechanisms with NEA's Committee on Nuclear Regulatory Activities (CNRA), responsible for the activities of the Agency concerning the regulation, licensing and inspection of nuclear installations with regard to safety. It also co-operates with NEA's Committee on Radiation Protection and Public Health and NEA's Radioactive Waste Management Committee on matters of common interest.

* * * * * * * * * * * *

Requests for additional copies of this report should be addressed to:

Nuclear Safety Division
OECD Nuclear Energy Agency
Le Seine St-Germain
12 blvd. des Iles
92130 Issy-les-Moulineaux
France

ACKNOWLEDGEMENT

Swedish Nuclear Inspection (SKI), especially Mr. Oddbjörn Sandervåg, and Jean-Pierre Bento from JPB Consulting have greatly aided in preparing this report. Without their devotion this work would not have been possible. Also the effort of the various liaison persons in all the countries replying to the questions made is duly acknowledged.

FOREWORD

The clogging of intake strainers for containment spray water in Barsebäck 2 in July 1992 renewed the focus of international regulators on safety questions associated with strainer clogging which, until then, had been considered as resolved. The event was followed by a period of very active development and testing. A workshop on the strainer issue was organised in Stockholm in January 1994 under the auspices of Principal Working Group No 1. Its results have been collated in the report NEA/CSNI/R(1994)14, Proceedings of the OECD/NEA Workshop on the Barsebäck Strainer Incident (Stockholm, Sweden), 1994.

The workshop revealed a quite confusing picture of the available knowledge base. Consequently, an international working group (IWG), also under the auspices of Principal Working Group No 1, was established in order to make a critical review and compilation of available experiments and other data related to the performance of ECC water recirculation. The IWG composed of regulators and their supporting organizations or contractors, research establishments, BWR Owners Group and insulation vendors. The IWG produced the report ”Knowledge Base for Emergency Core Cooling System Recirculation Reliability”, NEA/CSNI/R (95)11. The report was completed in February 1996.

Although several of the strainer clogging phenomena are similar for BWR and PWR, the report focused on BWR phenomena. A reason for this is probably the fact that the incidents of strainer clogging actually occurred in BWRs, and there was a general feeling that the strainer function of PWR was adequate e.g. for less sludge. Also the fact that steam relief directly to the containment, as in Barsebäck, only is applicable to a few plants may have contributed. On the other hand there could be differences in, for example, transportation and clogging characteristics of insulation debris and characteristics of failed coating which could warrant separate analyses. However, also PWRs use the mode of ECC re-circulation. Consequently, there is a need to consider clogging phenomena which are common to BWR and PWR. Some phenomena exist that are unique for PWR only.

A number of corrective actions have been taken in the NPPs around the world since 1992. For a number of plants, actions were taken as direct responses to requirements issued by regulating authorities, while for other plants back-fitting measures were introduced voluntarily or because of anticipated requirements. The actual actions taken as response to the strainer issue, and the rationale behind these actions, have never been reported internationally in a systematic fashion.

Due to these reasons CSNI decided to set up another international task force to revisit the strainer clogging issue. A second CSNI workshop was organised as a part of this effort, and its results are collected in the report: NEA/CSNI/R(2000)16, Workshop on Update of the Knowledge Base for Sump Screen Clogging, Proceedings, May 1999, Stockholm, Sweden. One of the further objectives of the task was to provide a survey of actions taken in the various countries. This report presents the findings of that survey.

TABLE OF CONTENT

1. EXECUTIVE SUMMARY

A review has been conducted of modifications performed primarily in the ECCS (Emergency Core Cooling System) and CSS (Containment Spray System) of nuclear power plants in different countries following the Barsebäck event in July 1992.

The information about these modifications has been gathered through a literature study of internationally published reports, contacts with the regulatory body from the different countries, and in some cases, directly from utility specialists and plant representatives.

The information reflects the plants and research status as per December 2001. It covers 15 countries encompassing nine countries with PWRs, seven with BWRs, five with VVERs and one country with CANDU-reactors.

The review indicates that:

1. Many countries have carried out very thorough and expeditious actions in response to the Barsebäck event, often within a noteworthy constructive co-operation climate between the regulatory body and the plant owners.
2. All countries have performed extensive studies.
3. Many countries have performed extensive experiments.
4. Corrective actions have been taken in:
   - most BWRs,
   - a limited number of PWRs and
   - a relatively significant number of VVERs and CANDU reactors (installation of new strainers / material).
5. Experiments and theoretical studies are still on going in some countries, mostly for PWR designs.

Studies and experiments

All countries covered in the report have performed extensive studies to assess the amount of insulation materials that could be dislodged during pipe break events inside the containment. In many countries, the analyses were based on the double cone model of the USNRC. The analyses have also included specific studies of the transport of insulation materials and other debris in the containment, and of strainer pressure drops.

The analyses were often conducted in parallel with extensive experiments utilising different insulation materials to assess the physical and time aspects of the clogging of the suction strainers. Many countries also performed mock-up studies. Full-scale tests were also performed in the condensation pool of some units.

The experiment results were utilised for the optimisation in most BWRs of new strainer designs, and for the choice of new thermal insulation materials.

The results obtained confirmed, mostly, the appropriate design of existing PWR strainers. PWR and Candu reactors related s studies and experiments are, however, still on-going in a few countries.

Strainer modifications

The modifications of the ECCS and/or CSS suction strainers have been performed after the aforementioned exhaustive studies and experiments. The modifications have resulted in new strainer designs with significantly enlarged filtering area. These modifications are summarised in Table 1.1.

Most of the new strainers have good self-cleaning properties. Relatively many of them have been provided with instrumentation for differential pressure measurement, with indications and alarms in the unit main control room, and at some units in the emergency control room. In some BWRs, the design encompasses the possibility to back-flush the strainers.

Replacement of insulation materials

Replacements of large fractions of the thermal insulation materials utilised on piping and other components inside the containment have taken place. The newly installed insulation materials vary both within and between countries. They are primarily RMI (Reflecting Metallic Insulation), nuclear grade fibreglass, mineral wool and calcium silicate. The same insulation material – for example mineral wool – can be installed differently in different countries, i.e. jacketed or encapsulated in cassettes. The results of the experiments have significantly contributed to the materials selected or installation methods.

Administrative measures

The administrative measures taken by plant owners include, e.g. a periodic cleanup of the suppression pool and the containment sumps, with the aim to minimise the presence of foreign materials, and the control and eventual betterment of the containment coating.

Finally, several plants have revised their Emergency Operating Procedures (EOPs) and other operating procedures, as well as the operating personnel training programmes, including presently simulator training on back-flushing measures.

Table 1.1: Summary of ECCS and CSS strainer modifications carried out in different countries after the Barsebäck 2 event in 1992 (situation as of 2001)

Country	PWR	BWR	ECCS & CSS strainer Modifications
Belgium	2 out of 7 units modified		6-fold area increase
Canada CANDU	 4 out of 18 units modified. 10 units to be modified		 New strainer design with 13-fold area increase
Czech Republic VVER-440/213 VVER-1000/320	 4 out of 4 units modified None of the 2 units modified		 New strainer design with 4-fold area increase
Finland VVER-440/213 (modified)	 2 out of 2 units modified	2 out of 2 units modified	About 10-fold area increase New strainer design with significant area increase
France	None of the 58 units modified		
Germany	 2 out of 13 units modified	4 out of 6 units modified	- Strainers were enlarged - Strainers were removed Strainers were enlarged
Hungary VVER-440/213	 4 out of 4 units modified		 New strainer design with about 50-fold area increase
Japan	 None of the 23 units modified	None the 28 units modified	More than 95% of the insulations are replaced by non-fiber type ones (e.g. Reflective Metal Insulation).
Netherlands	1 out of 1 unit modified		New strainer installed (50% area increase)
Spain	 None of the 7 units modified	2 out of 2 units modified	New strainers with significant area increase
Sweden	 1 out of 3 units modified	9 of the 9 units modified	New strainers with 15 to 40-fold area increase New strainers with > 7-fold area increase
Switzerland	 None of the 3 units modified	2 out of 2 units modified	New strainers with 7 to 30-fold area increase

Country	PWR	BWR	ECCS & CSS strainer Modifications
USA	None of the 69 units modified	34 out of 34 units modified	New strainers with significantly increased area
Russia Balakovo VVER-1000 Kola 2 VVER-440/213 2 VVER-440/230	None of the units modified All 4 units to be modified during 2002		Planned installation of significantly enlarged strainers of new design Installation of new strainers (same design as for Balakovo)
Slovak Republic VVER 440/213	4 out of 4 units modified		Strainers of a new design with significantly enlarged area

2. INTRODUCTION

NEA/CSNI/R (95) 11 report “Knowledge Base for ECCS Recirculation Reliability” indicates clearly the wide applicability of physical laws relating to debris generation and transportation in LWRs. The Canadian experience widens this applicability to CANDU reactors as well.

For BWRs, significant differences exist as regard to the containment design and location of wet-well strainers, even if the concept of pressure suppression containment is the same for all BWR units. A similar conclusion applies for the containment and sump design of PWR units.

Furthermore, considering the broad spectrum of insulation materials and types of encapsulation utilised around piping and vessels within the containment, it is obvious that the resolution of the strainer issue is a highly plant specific issue.

Based on the above considerations, the aim of the present report is to provide a survey of modifications of the ECCS and CSS sump strainers performed at nuclear power plants from different countries after the Barsebäck event in July 1992.

The present report is based on information about these modifications gathered through a literature study of internationally published reports, contacts with the regulatory body from the different countries, and in some cases, directly from utility specialists and plant representatives.

The countries covered in the review are listed in table 2.1

Table 2.1: Countries covered in the review of corrective actions taken after the Barsebäck event in 1992.

Belgium
Canada
Czech Republic
Finland
France
Germany
Hungary
Japan
Netherlands
Russia
Slovak Republic
Spain
Sweden
Switzerland
USA

3. BELGIUM

Seven PWR units are in operation in Belgium. These units are either from the Westinghouse or the Framatome design (Doel 3 and Tihange 2). Doel 1 & 2 are both 2-loop units. Doel 3 & 4, and Tihange 1-3 are all 3-loop units.

At Doel 1 & 2 the sump screen area was already increased in 1985, in the framework of the first decennial periodic safety reassessment, taking into account the requirements of NRC RG 1.82 Rev.0.

With consideration taken to lessons learned from the Barsebäck strainer event, to the requirements of NRC RG 1.82 Rev.1 and to performed analyses (no strainer experiment has been conducted in Belgium), the strainers at Doel 1 & 2 were subsequently enlarged at two occasions as indicated in table 3.1 below.

As a precautionary measure after the Barsebäck event, the recirculation flow at Doel 1 & 2 was limited by procedures to 288 m^3/hr - representing about 75% of the nominal flow – in order to minimize the pressure drop across the strainers. After increasing the strainer areas, the flow rate has been restored to the nominal value of 377 m^3/hr.

The models utilised for the calculations of the volume of debris generated were the double cone model for Doel 1 & 2, and the spherical model for all other units.

As also indicated in table 3.1, no strainer modification has been made in any of the other Belgian units. Calculations show however that the $NPSH_{margin}$ to ECCS- and CSS- pump cavitation at nominal recirculation flow rate is relatively small for some of the units. This issue is somehow still under discussion, but no tangible result has been reached and no corrective action has been decided yet.

Table 3.1: Strainer modifications performed at Belgian plants after the Barsebäck 2 event.

Unit	Strainer area		Insulation
	before modification	after modification	
Doel 1	3,9 m^2 *	15,5 m^2 (in 1994) 26,5 m^2 (in 1996)	Fibreglass
Doel 2	4,2 m^2 *	16,8 m^2 (in 1994) 23,5 m^2 (in 1996)	Fibreglass
Doel 3	46,6 m^2		Fibreglass – Mineral wool
Doel 4	46,7 m^2		Fibreglass – Nukon – Mineral Wool
Tihange 1	29,2 m^2		Fibreglass – Nukon – Mineral Wool
Tihange 2	34,1 m^2		Fibreglass – Mineral wool
Tihange 3	25,4 m^2		Fibreglass – Nukon – Mineral Wool

* The original sump screen area of Doel 1 (Doel 2) was already increased in 1985 to this value.

References:

1. AVN, “The treatment of the sump screen clogging issue in Belgium”, OECD/NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
2. Leblanc, O., TEE, “Criteria for increasing sump screen area in the Belgian PWRs Doel 1 & 2”, OECD/NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
3. Van Binnebeek, H., AVN, private communication, February 2001.

4. CANADA

18 CANDU reactors are presently operating in Canada.

The ECC strainer(s) located at the ECC pump intake are credited with being able to tolerate large volume of fine debris without reducing the pump NPSH below an acceptable value.

In the late 1990's, Canadian utilities started to examine in detail the issue of potential ECC strainer clogging by LOCA generated debris. Extensive testing has been performed since then by the CANDU Owners Group at Atomic Energy of Canada's Chalk River Laboratories. The testing included head loss testing using several geometries of small-scale strainers, many different debris types and various flow rates, temperatures, etc. Other testing involved determining the short and long-term erosion characteristics of rigid insulation types subjected to flowing water typical of a post-LOCA environment, rate of travel for various types of debris, and mechanical and physical characteristics of various debris types. Some testing was still in progress in July 2001.

In addition, some privately funded tests (AECL or Ontario Power Generation) such as jet impingement tests and large scale prototype Finned Strainer ™ (Finned Strainer is a registered Trademark of AECL) tests have also been performed.

Based on the tests, some stations have resolved how they will deal with the potential for strainer clogging, while others are still considering various options.

- Pickering B (4 units) replaced the original strainers with the AECL-designed and supplied Finned Strainer. The last strainer was replaced in March 2001.

- Point Lepreau (1 unit) is in process of replacing the original strainers with two Finned Strainer units. The dual strainer arrangement provides redundancy. The replacement is scheduled during the spring 2002 outage.

- Gentilly 2 (1 unit) is in process of replacing the original strainers with two Finned Strainer units. Completion of the replacement is also scheduled for spring 2002.

- Darlington (4 units) is still considering options, but the final solution will include a larger strainer.

- Pickering A (4 units) is in the process of replacing the original strainers with larger ones.

- Bruce B (4 units) has decided to use the original strainer and will replace calcium silicate insulation with fibrous insulation that will not have as severe an impact on the strainer (which is shared by all four units).

Table 4.1 provides a comparison between the old and new strainers at CANDU stations currently in the process of replacing their original strainers.

Table 4.1: Strainer modifications performed at Canadian plants after the Barsebäck 2 event.

Station	Rated flow (L/s)	Old area (m^2)	New area (m^2)	Old footprint (Strainer floor area) (m^2)	New footprint (m^2)	ECC strainers per unit
Point Lepreau	605	6	79	1,1	~12	2[a]
Gentilly-2	605	6	100	1,1	~14	2[a]
Pickering B (four units)	707	~9	110	~3	22	1
Embalse[c]	605	6	*100*	1.1	*~15*	1[b]
Cernavoda[d]	605	6	*79*	1.1	*~12*	2[a]

Values in italics have not been finalized.

[a] One 100% capacity strainer per pump, only one pump is used at a time (two pumps are available).
[b] Two pumps connected to one 100% capacity strainer, only one pump typically operating at a time.
[c] This station is located in Argentina.
[d] This station is located in Romania.

The Finned Strainer™ units designed and manufactured by Atomic Energy of Canada Limited for retrofit into these stations are very compact, allowing a large surface area for filtering to be installed in a small space, which allows them to fit into crowded plants. They are also modular, allowing flexibility in the layout and size.

Considerable effort has been expended in Canada to characterize and quantify debris that may reach the ECC strainers. One of the main postulated sources of debris is from the feeder cabinet, which is an insulated room in CANDU stations containing hundreds of feeder pipes carrying heat transport fluid (heavy water) to and from the reactor core. If any of these pipes burst, the resulting jet could dislodge large quantities of insulation debris from the walls, which may be transported to the strainer(s) in the basement. Other potential sources of debris from this and other rooms include calcium silicate (from pipe insulation and energy-absorbing pads), rust, dust, dirt and paint.

For the CANDU stations listed above, models generally predict that approximately 10 m^3 of fibrous debris and lesser quantities of other debris types may reach the strainer, although the amounts vary depending on the break size, location and the particular station's debris types. In some plants, the quantity of calcium silicate pipe insulation that could reach the strainers has been a concern, so measures are being taken to remove or protect some of this material, and to prevent its use in new plants.

Reference:
Eyvindson, A., AECL, E-mail communications, June-July 2001.

5. CZECH REPUBLIC

Four VVER-440/213 are presently operating at the Dukovany nuclear power plant. Another two PWR units, VVER-1000/320 with a number of upgrading changes of original design, are being commissioned at the Temelin nuclear power plant. The first unit at Temelin is in the process of start-up and commercial operation will start in a near future. Physical start-up of the second unit is expected by the end of the present year.

Considerable efforts have been devoted at both NPPs to examine and resolve details of the sump screen clogging issue.

NPP Dukovany

The screen clogging issue at Dukovany was already considered in 1991 – 1992. In the framework of the decennial Operational Safety Report re-assessment, the decision in 1995 of the State Office for Nuclear Safety committed the licensee to assess the screen clogging potential and to implement corrective measures, if necessary. In 1996 – 1998 a number of analyses and tests were performed:

- Estimates of the quantity of dislodged insulation were made in accordance with the 7L/D double cone criterion for LB LOCA with guillotine break of the main circulation pipe. The break was located at the connection of the cold leg to the SG collector.
- Jet impingement tests and studies of insulation fragmentation were performed on the dynamic experimental facility of GOSNICAES.Kashira, Russia.
- Characteristics of the insulation materials and debris types, and rate of debris transport to the screen strainers were investigated at the Research Institute of Energetic Installations (VUEZ), Levice, Slovakia. The same organisation performed a series of strainer clogging tests on the mock-ups of the original and modified screens.
- Analyses of the pressure and water level drops during various LOCA accidents, for assessing and setting the acceptable values for these parameters.

It was shown that screens of the original design were not capable to fulfil the required safety functions in the whole expected range, and that corrective modifications were necessary. The final and most important modifications of the screens were:

- The original multi-row arrangement of internal strainers was replaced by module arrangement (19 or 22 box segments, according to the screen shape) and the inlet strainer with 10 x 10 mm mesh was replaced by perforated metal sheet with 10 mm diameter holes. This arrangement has also a good gravitational self-cleaning effect.
- The total area of internal strainers was increased from the original 5,05 m2 to 19,8 m2 for one screen (there are three screens in the containment, located at the sump inlets).
- Finer wire with square mesh was used for inner strainers (originally it was 0,63 mm diameter wire with 2 x 2 mm mesh, and is presently 0,4 mm wire with 1 x 1 mm mesh).

The original area and volume parameters of screens were unchanged, similarly as the total water flow through the screens. The screen inlet is protected by a cover grid structure. The water flow was reduced from the original 6 cm/s to 1,4 cm/s. Each sump is equipped with water level measuring device working with a binary signal and providing indications and alarms to both the main and the emergency control rooms. The mentioned modifications were fully implemented at all units by the year 2000.

NPP Temelin

Analyses of the strainer clogging risk were performed, in compliance with request from the State Office for Nuclear Safety, within the framework of the plant modernisation during its construction. The range of the risk was evaluated in a similar approach as for NPP Dukovany, in accordance with US NRC RG 1.82, Rev.1, and for the quantification of dislodged insulation the 7L/D criterion was used. The reference accident used in the dislodged insulation quantification was LB LOCA with double-ended cold leg break under the steam generator.

The water tank of the ECCS/CCS is L-shaped with legs length 21,9 and 16,6 m, width 5,7 m and height 3,5 m. The tank total volume is approximately 600 m^3. The tank has three inlet shafts protected by grids. The actual strainer sets (3 sets) are in a vertical position behind the shafts. One set is composed of 6 strainers with square mesh: one inlet screen with 10 x 10 mm mesh (2 mm wire), and five screens with 0,7 x 0,7 mm mesh (0,32 mm wire). The first and the last screens cover the whole flow area, and the four internal ones are arranged as a meander. The total effective area of one strainer set is 63,4 m^2.

The range of analyses and tests was essentially the same as for NPP Dukovany, and experimental tests were performed at the same organisations. The first stage of analyses and tests has indicated that the strainer capacity is adequate. For the final experimental verification, VUEZ has built a mock-up width-scaled 1:6 and height-scaled 1:4. All six strainers were modelled within 10 separate tests, which verified the efficiency of the strainer elements.

The results proved that the strainer functionality is sufficient and that no hardware modification is needed. In the present design, the water level is measured in front of the coarse inlet strainer and after the last fine one, by three independent measuring chains (qualified for LOCA conditions). The water level is indicated in the main and the emergency control rooms, and the EOPs (for loss of emergency recirculation) were appropriately revised.

Reference:
Jakab, J., Nuclear Reaseach Institute Rez plc, E-mail communication, January 2002.

6. FINLAND

Four units are in operation in Finland. Olkiluoto 1 & 2 are ABB-Atom BWRs with internal primary recirculation pumps and a containment similar to GE Mark III containment. Loviisa 1 & 2 are PWRs of eastern design (modified VVER-440 V213).

BWRs

All safety systems in Olkiluoto 1 & 2 have four redundant trains. Accordingly, both the low pressure ECCS and the CSS (Containment Spray System) have 4x50% capacity. Each train of the low pressure ECCS and of the CSS shares a common suction strainer located in the wet-well (condensation pool).

Each of the four suction strainers is a double-sided 3x3 m panel with an effective area of 32 m^2. The strainers are perforated with 4 mm diameter holes.

In the original design, provisions for manually initiated backflushing of these strainers with compressed air were included, despite no indication of the need for strainer backflushing was originally demonstrated.

The Barsebäck incident indicated that assumption on the volume of insulation debris reaching the wet-well was not necessarily conservative.

After discussions between the Finnish utility (TVO) and the regulator (STUK) it became evident that the mineral wool insulation used in the containment of Olkiluoto 1 & 2 had not been qualified to justify the application of US NRC 1.82.

STUK requested that the assumed zone of total destruction of the insulation shall be within a 7L/D 90^o double cone centred at the postulated pipe break location and extended to the nearest major wall boundaries. No credit is taken for leak before break (LBB) and similar alleviating arguments.

The insulation is postulated dislodged instantaneously and transformed into fibres for sump strainer clogging. No credit being taken for gratings or other obstructions.

With these discussions as input, exhaustive calculations and experiments were performed. These investigations have indicated that the original design basis of the strainers was most probably valid for postulated LOCA. The design of the strainer was thus not modified.

Although this result, the utility decided to upgrade the backflushing function, replacing compressed air by compressed nitrogen, and increasing the volume of nitrogen in each step of the backflushing sequence. Furthermore, the strainers were equipped with differential pressure measuring equipment, with indications and alarms in the main control room.

Other modifications encompass the montage of collars around the blowdown pipe inlets on the dry-well floor, and replacement of the fibrous insulation of the main steam lines and other large diameter pipes with

RMI (Reflecting Metallic Insulation). The mentioned modifications were implemented until 1993. After that date, replacement of fibrous insulation by RMI has been continued.

Mention has to be made that the Finnish regulator STUK based the approval of the strainers, for Olkiluoto as well as for Loviisa, on extensive testing under as prototypic as possible conditions.

PWRs

Both Loviisa units are VVER-440/V213. The soviet design of the plant was originally modified. Both units have for example a western containment design with ice-condenser, and western control systems.

The first sump screens designed for the Loviisa units were based principally on the standard VVER-440/V213 sump design. The sumps were double vertical outlet sumps (2x100%) surrounded with multiple screens (one 10x10 mm mesh screen and seven 2x2 mm mesh screens) without bypass between separate screens. No partition between the two inlets was provided for in the original sump design.

The sumps were modified on the request from the Finnish regulator STUK already in 1976 and 1979. The modifications resulted in increased effective sump screen area and in the installation of additional 10x10 mm mesh screen walls apart from the sumps.

In response to the Barsebäck incident, a reassessment of debris generation and transport was performed for the Loviisa units. The calculations were made based on STUK request that the assumed zone of total destruction of the insulation shall be within a 7L/D 90^o double cone centred at the postulated pipe break location with the largest amount of insulation. The insulation is postulated dislodged instantaneously and transformed into fibres for sump strainer clogging. No credit being taken for gratings or other obstructions.

Based on this reassessment, a temporary modification was made on both units during the refuelling outage of 1992. The modification consisted in reducing the mesh size of the outermost screen walls from 10x10 mm to 2x2 mm, thus increasing the debris capturing capability.

In the mean time a new sump concept was studied. The new sump strainers were installed during the refuelling outage of 1993. The new strainers are made of several cylindrical parts perforated with 2 mm holes and installed vertically in parallel. The effective area of the strainer is almost 100 m^2.

Despite good self-cleaning properties, these strainers have been equipped with differential pressure measurement, with indications and alarms in the main control room. Furthermore, the new strainers have manually initiated and operated nitrogen backflushing capability. The grace time for operator actions in case of the highest expected pressure difference gradient across the strainers is more than five hours.

References:
1. Koski, S., TVO, “Implications of the Barsebäck strainer incident for the Finnish BWRs”, presentation at the OECD/NEA Workshop on the Barsebäck strainer incident, Stockholm, January 1994.
2. Hyrsky, T. & Kleemola, T., IVO, “Sump strainers at the Loviisa plant”, presentation at the OECD/NEA Workshop on the Barsebäck strainer incident, Stockholm, January 1994.
3. Laaksonen, J., STUK, “Resolving of the sump screen clogging issue in Finland”, Memorandum, March 1999.

7. FRANCE

58 standardized PWRs of Framatome/EdF design are in operation in France.

The N4 and P4 - P'4 series are of the 4-loops design.

The CP1 - CP2 series are of the 3-loops design and both the ECCS and the CSS have two redundant trains. A large debris screen with a mesh size of 20 mm is common to the four trains of the ECCS and CSS.

The six units of the CP0 series (2 units at Fessenheim NPP and 4 units at Bugey NPP) are similar to those of the CP1 – CP2 series, but are of a former design. The sumps installed in the Bugey units are similar to those of the CP1 – CP2 series. The Fessenheim units have large debris screens that are common to the two trains of each system.

Valid for all 3-loop series, each train has a three screens sump according to table 7.1.

Table 7.1: Some characteristics of ECCS and CSS strainers in the French PWRs.

Series	**Net output (MWe)**	**Units in operation**	**Sump screen area (m^2)**	**Sump screen mesh size (mm)**
N4 (4 loops)	1450	3	ECCS: 2 x 43 CSS: 2 x 43	One coarse screen and 2 fine screens 12 x 12 2,5 x 2,5
P4-P'4 (4 loops)	1300	20	ECCS: 2 x 37 CSS: 2 x 37	30 x 30 12 x 12 2,5 x 2,5
CP1-CP2 (3 loops)	900	28	ECCS: 2 x 15 CSS: 2 x 15	11, 8 x 11,8 4,5 x 4,5 2,5 x 2,5
CP0-Bugey (3 loops)	900	4	ECCS: 2 x 13 CSS: 2 x 13	2 coarse screens and one fine screen 2,5 x 2,5
CP0-Fessenheim (3 loops)	900	2	ECCS: 2 x 10 CSS: 2 x 10	2 coarse screens and one fine screen 2,5 x 2,5

Based on analyses and experiments, the state-owned utility Electricité de France (EdF) has concluded that the pressure drop across the sump strainers of the French PWRs is low. Accordingly, EdF has assessed that the risk for strainer clogging in case of LOCA is remote.

Modifications performed by EdF as regard to the strainer clogging issue has until now been mostly limited to the refurbishment of the sump painting/coating at some units.

More recently, some degradation of the coating on the inside walls of the containment has been identified at some units. This degradation will eventually result in new analyses concerning the amount of particles that can be released during a LOCA, and their transport to the containment sump.

In order to check the studies made by EdF, additional studies are in progress at IRSN (Institut de Radioprotection et de Sûreté Nucléaire). These latter studies should be completed by September 2002. For the future, EdF is considering to modify some assumptions regarding the behaviour of the insulation materials inside the containment in case of DBA (Design Basis Accident). A survey of studies and tests performed internationally has been initiated for this purpose.

References:

1. Clausner, J.P., DGSNR, private communication, February 2001
2. Fourest, B., EdF, private communication, February 2001.
3. Prigent, A., EdF, private communication, June 2001.
4. Armand, Y., Bertrand, R,. IRSN, E-mail communication, April 2002.

8. GERMANY

19 LWRs are in operation in Germany. The BWRs are of the KWU design (four BWR/69 and two BWR/72). The 13 PWRs are of KWU design (eight units) and of Siemens design (5 units). One PWR (Obrigheim) is of 2-loop design, Neckar GNK 1 is of 3-loop design and the remaining 11 PWR units are of 4-loop design.

The German "basis safety" concept is important to mention as an introduction to modifications performed in the German plants. According to this basis safety concept, the complete rupture of reactor primary coolant pipes, main steam lines and main feedwater lines can be excluded for most plants. The exception concerns the four older 1300 MWe PWR units, because of formal reasons.

The modifications implemented in the German plants were based on a postulated 0,1 A (i.e.10% of pipe sectional area) break in the reactor coolant line (or equivalent) for PWRs, and on a conservatively postulated double-ended main steam line rupture for BWRs.

BWRs

The most frequently utilised insulation materials in all German BWRs are ISOVER, a relatively heavy mineral wool, and Minileit. Both are extensively installed in cassettes. Reflecting metallic insulation is installed at some units.

Based on results from experiments and calculations, no hardware modification was needed in the two units of the BWR/72 design (Gundremmingen B & C).

In order to further reduce the probability for strainer clogging in the units of the BWR/69 design, plant specific hardware modifications were implemented in two main areas:

- The sump was covered with a perforated plate to reduce the amount of debris washed into the sump.
- The strainers in the suppression pool were modified or removed.

Concerning the second area, one BWR unit installed significantly enlarged strainers in the condensation pool. The strainers were designed for high differential pressure.

Other units removed or cut large holes (for example Krümmel and Brunsbüttel) in the pool strainers to prevent their clogging. The possibility to perform such modifications in the German units relates to the fact that strainers close to the recirculation pumps can perform the filtering task of the condensation pool strainers. These strainers are larger than the pool strainers, thus resulting in a lower risk for significant NPSH drop due to clogging. Furthermore, the pump strainers are outside the primary containment and accessible for cleaning during operation.

An update of the types and masses of insulation materials installed in the containment has been performed at all BWR units. Some fibreglass insulation was assessed to be susceptible to ageing effects and was replaced by mineral wool.

Another example of corrective actions taken at German BWRs was the removal at some unit of the insulation around colder or smaller piping not normally utilized during power operation. In this specific case, the amount of insulation removed had to take into consideration the capacity of the containment ventilation system.

All plant modifications related to the strainer issue were completed at the German BWRs mainly until 1996. No further modification is presently planned in relation to this issue.

PWRs

As indicated above, the four oldest PWR units do not, for formal reasons, fulfil the German “basis safety” concept. Therefore, a guillotine break of a primary loop had to be assumed for these four units.

In the German PWRs, as mentioned earlier for the BWRs, the insulation materials are generally encapsulated in cassettes. Calculations performed for all German PWRs indicate that the NPSH drop due to strainer clogging will not cause cavitation of the recirculation pumps.

Based on investigations and experiments, only a few German PWR units have performed strainer modifications. The sump strainer area was enlarged at two plants. One plant replaced at specific locations mineral wool by “Minileit” insulation, thus contributing to a lower probability for strainer clogging.

Finally, the backflushing of pool and/or sump strainers is not foreseen as a corrective measure in the accident procedures for German plants. However, some units are training on simulators their operating personnel on backflushing measures.

References:

1. Maqua, M., GRS, “Status of the actions taken in Germany after the Barsebäck event”, OECD/NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
2. Ohlmeyer, H., HEW AG, “State of performed studies, experiments and plant modifications for German BWR plants caused by the Barsebäck incident, OECD/ NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
3. Däuwel, W. et al, Siemens, KWU, “Survey of studies concerning ECCS reliability of German PWRs in the light of the Barsebäck event”, OECD/ NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
4. Ohlmeyer, H., HEW AG, “Investigations and modifications in the German BWR-plants KKB and KKK after the Barsebäck incident”, OECD/NEA Workshop on the Barsebäck strainer incident, Stockholm, January 1994.

9. HUNGARY

Four VVER-440/V213 are in operation in Hungary. The four Paks units have during the years been improved in co-operation with western companies and organisations.

Relating to the strainer issue, mineral wool insulation is widely used in the VVER units. Insulation behaviour tests were performed with different insulation materials during the construction phase of the Paks units. The test made in Finland and in Zaporozhe in Ukraine confirmed that, in the case of complete dislodging of the thermal insulation following a pipe break, the originally designed sump strainers could be blocked. This resulted early in increased strainer area.

Following the Barsebäck incident, new full scope model tests were performed in 1995 – 1996 at the Power Plant Process Laboratory of IVO in Finland. These tests resulted in a new screen structure based on the strainer element developed at IVO International.

The new screen structure consists of two separate strainer elements with similar construction but different heights and connecting collectors. In the new elements, horizontal, vertical and inner surfaces can filter debris. A cleaning possibility by manually initiated air discharge (backflushing) is incorporated in the design, and in addition the strainer elements have a self-cleaning feature.

The new strainer elements are installed horizontally on the floor. The location is such that all filtering surfaces will be submerged during the recirculation phase. The strainers are protected by a cover plate.

Later experiments showed that the pressure drop across the strainers is negligible. Consequently, the backflushing air system was not installed in the units.

The installation of the new strainers in all units was completed during the refuelling outage in 1997. The main characteristics of the strainers are provided in table 9.1.

Table 9.1: Main characteristics of the strainer implementation at the Paks units.

Characteristics	**Before modification**	**After modification**
Strainer area	3 x 1 m^2	160 m^2 54 “A” elements with 2,5 m^2 14 “B” elements with 1,8 m^2
Theoretical retention capacity of fibrous mineral wool	75 – 90 kg	780 kg
Coarse debris screen mesh size		50 x 100 mm
Strainer mesh size (perforated plate)		2 mm

Reference:
Tóth, J., Paks NPP, E-mail communications, March-April 2001.

10. JAPAN

Japan has 28 BWRs and 23 PWRs in operation. The first BWR build in Japan was designed by GE and the first PWR designed by Westinghouse. These plants and most of subsequent plants designed by Japanese manufacturers have been modified in the improvement and standardization program jointly promoted by the regulatory body and the industry. The improvements have incorporated lessons learned from domestic and overseas incidents and accidents.

In response to the Barsebäck incident, the electric power companies did plant examination and reported their results to MITI (nowadays METI) in 1994. The examination results showed that more than 95 % of the fibre insulation, like asbestos and mineral wool, had been already replaced with RMI and calcium silicates in both BWR and PWR. These early replacements were made in consideration of the reduction of occupational radiation exposure and of the enhancement of environmental working condition.

BWRs

The electric utilities with operating BWRs and the plant manufacturers have conducted evaluations of the potential ECCS strainers blockage for typical reference BWRs with Mark-I and Mark-II containment. The estimation of debris generation following a LOCA was performed conservatively postulating a double-ended guillotine break by use of 45^0 cone model of NUREG-0897 (Rev.1).

Calcium silicate was a dominant contributor to NPSH reduction following a LOCA and pressure drop experiments were performed. The evaluations showed that available NPSH were sufficient to satisfy the required values without any modifications of existing ECCS strainers for those BWR plants with Mark-I and Mark-II containment.

The non-presence of foreign materials in the suppression pool of the Japanese BWRs is ensured through the following operational and maintenance practices:

- Foreign materials are eliminated from inside the containment by cleaning and inspection before start up at every refuelling outage.
- The suppression pool is inspected at every refuelling outage.
- The suppression pool is emptied and cleaned at appropriate intervals, as well as surface repainting is performed.

PWRs

The electric utilities with operating PWRs and the PWR plant manufacturers have performed the evaluation of potential blockage of the recirculation sump screens for a typical reference PWR. The estimation of debris generation following a LOCA was done conservatively using 45^0 cone model in NUREG-0897 (Rev.1). The effect on the available NPSH by debris transportation to the recirculation sumps was evaluated. Evaluation results showed that available NPSH was sufficient as compared with the required value and also with consideration taken to safety margins.

The non-presence of foreign materials in the recirculation sumps of the Japanese PWRs is ensured through the following operational and maintenance practices:

- Foreign materials are eliminated from inside the containment by cleaning and inspection before start up at every refuelling outage.
- Inspection of the recirculation sumps is performed during every refuelling outage.

Reference:

Tamao, S., NUPEC, E-mail communication, November 2001.

11. NETHERLANDS

One PWR of the Siemens/KWU 2-loop design is in operation in The Netherlands. The ECC sump system is a system with two redundant trains which has the following parts per train:

- Drain sump
- Debris curb
- Trash rack (30x30 mm)
- Two debris screens (10x10 mm and Ø5 mm) and (2x20m^2 and 2x8.9m^2).

In 1980 the debris of the thermal insulation that could be generated by a LOCA was considered to be a potential problem and was addressed by changing from mineral or fibreglass wool to full metal insulation with dimpled inner sheeting. At the time of the occurrence of the Barsebäck event, some amounts of mineral and fibreglass insulation were still present in the installation. A direct improvement was executed by installing an extra screen with a large area (20 m^2) per redundant train during the 1993 outage.

Since the outage of 2001 there is no mineral or fibreglass insulation of noteworthy importance around the primary components as well as in the sump-area. The screens have a significant over-capacity for holding back debris and insulation.

The original coating-systems used in the sump were LOCA resistant. A study in 1997 showed that because of degradation processes this LOCA resistance could not be guaranteed on all surfaces. In 1999 and 2000 the degraded surfaces where either renewed or fixed by stainless steel screens.

During the Plant modification project in 1997, the German "basic safety" concept was implemented. According to this basic safety concept, the complete rupture of reactor primary coolant pipes, main steam lines and mean feedwater lines can be excluded. This reduced the likelihood of a LOCA.

With all these measures the probability of strainer clogging needs not to be considered any further.

<u>References</u>:

1. Aanzuigcondities reactorput (Suction conditions for ECC sump performance) Rapport nr. 188.87.05; 5 Juli 1987; R. Di Giorgio.

2. Evaluatie en analyse van te nemen maatregelen voor de Nucleaire Produktie te Borssele naar aanleiding van de storing: "Losraken isolatie door aanstralen uit geopende veiligheidsklep, met als gevolg verstoppen aanzuigkorven van het containment-spraysysteem in de kernenergiecentrale Barsebäck".; (Evaluation of the event and analysis of the measures to be taken for the NPP Borssele as a result of the Barsebäck event); Rapport R92.0275; December 1992; R.B.C. Koopman .

3. Invloed van de coating van de reactorsumpf op TJ-putbedrijf. (Influence of coating of the sump area on ECC sump performance); Rapport nr. R0282 rev. 3; 10 Juli1997; W.A.G. van der Mheen.

4. Sumpfbedrijf reactor Borssele. Evaluatie van de risico's van coatingonthechting na een LOCA. (ECC sump performance, evaluation of risk of coating-debris after a LOCA);

5. Rapport AZ/R28012001; 29 Januari 2001; ir. A.G. Zilverentant - DHV Water BV

6. “Rest risico voor falen van putbedrijf als gevolg van loskomende vloer- en wandcoating” (Remaining risk of failing ECC sump performance due to detatchment of floor- and wallcoating); R002304 rev. 1, september 2001.

7. Van Beuzekom, NPP Borssele, E-mail communication, October 2001.

12. RUSSIA

Information pertaining to plant modifications performed in nuclear power plants in East & Central Europe has, for the most part, only been received from third party. According to this information strainer modifications have been implemented in both VVERs 440 and VVERs 1000 in some of the mentioned countries.

The modified ECCS strainers have basically a design similar to the one of the new strainers in Paks and Loviisa VVERs.

Balakovo NPP

The Balakovo plant has five 1000 MWe VVER-320 in operation. A project "Sump filter system upgrading design for 1000 MW standard plant in Russia, project number TACIS R2.08/94N" within the EU TACIS programme was performed during 1995 – 1996. The Finnish company IVO Power Engineering Ltd was the main contractor for this project. The aims of the project were:

- Analyses of flow conditions inside the containment during recirculation.
- Assessment of debris generation.
- Studies of ECCS pump suction conditions after a LOCA.
- Development and design of new containment sump strainers.

The proposed design is based on a predicted debris load of 850 kg during a LOCA. This design was accepted, after verification tests with the Russian regulatory body GAN (Gosatomnadzor), for later implementation. The new filtering area of the ECCS strainers is > 350 m^2, and the strainers mesh size is 2 x 2 mm, with a wire diameter 0,7 mm. Tubular elements constitute the inner strainer surface.

Reference:
Tarkiainen, S., FORTUM, E-mail and private communications, June 2001.

Kola NPP

The Kola plant has four 440 MWe VVER reactors in operation. Unit 1 and unit 2 are VVER-440/230. Unit 3 and unit 4 are VVER-440/213.

Analyses and experiments comparable to the ones performed for Balakovo have been conducted for Kola with Nordic funding. The retained design of the new sump strainers is based on a predicted debris load of 275 kg during the dimensioning hot leg LOCA, and of 360 kg during the dimensioning cold leg LOCA.

The proposed design has a filter area exceeding 50 m^2 with a wire mesh 2 x 2 mm used for the filtering surface. The stainless steel wire diameter is 0,7 mm. Vertical plates constitute the outside filtering surface.

The project for the upgrading of the sump strainers is on-going, and the installation of the new strainers is planned for year 2003 for unit 3, and year 2004 for unit 4. Similar modifications are planned later on for the units 1 and 2.

Reference:

Rudenko, A.M., Kola nuclear power plant, E-mail communication, December 2001.

13. SLOVAK REPUBLIC

The Bohunice plant has two 440 MWe VVER 440/230 and two VVER 440/213 in operation.

A project "Design of new sump filter, and insulation tests, project number PHARE 2.05/95" within the EU PHARE programme was performed in 1997. The Finnish company IVO Power Engineering Ltd was the main contractor for this project. The project had the following aims:

- Assessment of flow conditions, debris generation and transport.
- Insulation destruction test with different insulation materials.
- Development and design of new containment sump strainers.

The project also encompassed comparative testing with existing strainers proving the necessity to implement the strainers of the new design. The new filter area is 20,5 m^2 for predicted 1100 kg of debris after a LOCA. The new strainer design has box elements as inner filtering surface.

The new containment sump strainers were implemented at the Bohunice units during year 2000.

Reference:
Tarkiainen, S., FORTUM, E-mail and private communications, June 2001.

14. SPAIN

Spain has nine operating LWRs. Six of the seven PWRs are of Westinghouse design and one is of KWU design. The two BWRs are of GE design.

Zorita, PWR, 1-loop design.
Garoña, BWR-3, Mark I containment.
Almaraz 1 & 2, PWR, 3-loop design.
Ascó 1 & 2, PWR, 3-loop design.
Cofrentes, BWR-6, Mark III containment.
Vandellós 2, PWR, 3-loop design.
Trillo, PWR (KWU), 3-loop design.

BWRs

The position of the Spanish nuclear regulator CSN (Consejo de Seguridad Nuclear) has been from the beginning that the concerns and lessons related to the Barsebäck 2 event were fully applicable to the two Spanish BWRs.

The strainers at both BWRs were modified to the “cassette” design in 1997 and 1999. The strainer area has been significantly increased at both plants in order to reduce the pressure drop across the strainers. The gross area of the new strainers in Garoña are 68 m^2 and in Cofrentes 27 m^2.

Related to the strainer modifications and to the issue of long-term cooling, the plants have performed new $NPSH_{margin}$ calculations during years 1998-1999. These analyses have been reviewed and approved by the CSN.

During years 1998-2000, the plants have controlled, inspected and improved the protective coatings in the containment and the painting in the suppression pool. The Spanish BWRs have also established a periodic complete emptying and cleaning of the suppression pool. At Garoña – not assessed necessary for Cofrentes - for each such cleaning operation, plant procedures include instructions for the characterisation and inventory of the collected material, thus allowing a comparison of the collected inventories with the assumptions in the hydraulic calculations.

In addition, the plants have revised their Emergency Operating Procedures (EOPs) and other operating procedures, as well as the operating personnel training programs. Some of these actions are summarized in table 14.1 below.

PWRs

The assessment made by the Spanish regulator and utilities is that vulnerability of the Spanish PWRs to the strainer clogging issue is low. Among the main reasons for this assessment are the larger areas of the sump strainers, and the smaller generation of debris following a LOCA. The latter is based on the fact that the containment is divided into smaller compartments.

Based on this assessment, no strainer modification has been considered necessary, up to now, in the Spanish PWRs. New calculations of the $NPSH_{margin}$ for the ECCS pumps have been performed at all units and reviewed by the CSN.

In addition, the control of the protective coating in the containment has been completed.
Further actions are not actually planned. A summary of actions taken at the Spanish PWRs is presented in table14.1.

Table 14.1: Main actions taken at Spanish LWRs after the Barsebäck 2 event.

Action	Year	BWRs	PWRs W	PWR KWU	Comments
Control of temporary fibrous sources in containment	1993	Yes	Yes	No	Main issues: housekeeping & FME practices
Compensatory measures: • Training • EOPs • Operating strategies & procedures	1994	Yes	No	No	Issues: • Available means to detect strainer clogging • Manual strainer back-flushing (only Cofrentes) • Strategies to minimize the ECCS recirculation flow
Strainer performance Surveillance during power operation	Since 1994	Yes*	No	No	*Only in Cofrentes
Cleaning of suppression pool & inspection of strainers	Since 1994	Yes	No	No	
Installation of larger passive Cassette-strainers	1997 & 1999	Yes	No	No	
Assessment and update of NPSH-margin calculations	1997-1999	Yes	Yes	Yes	
Control of containment Protective coating	1998-1999	Yes	Yes	Yes	Issues: qualification & inventory of unqualified coatings
Inspection & improvement of condensation pool painting	1999-2000	Yes*	No	No	*Only in Garoña
Condensation pool water cleanliness surveillance & control during power operation	Since 1999	Yes	No	No	

References:
1. Diego Encinas, CSN, “Actions taken in Spanish NPPs after the Barsebäck incident”, OECD/NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
2. Diego Encinas, CSN, “Assessment of new strainers for two Spanish BWRs”, OECD/ NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
3. Diego Encinas, E-mail communication, Mars 2001.

15. SWEDEN

Eleven units are presently in operation in Sweden (Barsebäck 1 was permanently shutdown at the end of 1999). Eight are BWRs of ABB-Atom design and three are 3-loop PWRs of Westinghouse design.

BWRs

The eight BWR Swedish units belong to four design generations according to the following:

- First generation: Oskarshamn 1 & Ringhals 1 (external primary recirculation pumps. Containment similar to GE Mark II containment).
- Second generation: Barsebäck 2 & Oskarshamn 2 (external primary recirculation pumps. Containment similar to GE Mark II containment). Barsebäck 1 was also operating in 1992 and closed in 1999 for political reasons.
- Third generation: Forsmark 1 & 2 (internal primary recirculation pumps. Containment similar to GE Mark III containment).
- Fourth generation: Forsmark 3 & Oskarshamn 3 (internal primary recirculation pumps. Containment similar to GE Mark II containment).

The reactors of the two oldest generations were temporary shut down by the regulator after the incident at Barsebäck 2. For these units, the modification programme was taken in two steps with the following objectives:

- To restore the function of the low pressure ECCS and CSS (Containment Spray System) to the level assumed in the unit's FSAR prior to the Barsebäck event.
- To increase the area of the low pressure ECCS and CSS strainers to make backflushing during the first 10 hours after a LOCA unnecessary.
- To reduce the amount of insulation material that could be dislodged and transported to the wet-well.

Following exhaustive calculations and experiments – some full scale experiments were conducted utilizing the wet-well at some units – the low pressure ECCS and CSS strainers of the units with external primary recirculation loops were replaced with significantly larger strainers, i.e. by a factor of 15 – 40, se table 15.1 below. Most of the modifications were completed during the annual maintenance outages in year 1993.

The new strainers consist of vertical cylinders perforated with 3 mm holes. Each strainer set has a flushable strainer of approximately 1 m^2 area.

During the investigations, it was also assessed that the insulation material on the reactor pressure vessel – a composite of calcium silicate and asbestos (Caposil) – in small amounts of about 10 kg could in combination with mineral wool insulation clog the strainers. To prevent such consequences, reflecting metallic insulation (RMI) or nuclear grade fibreglass has replaced the calcium silicate on parts of the reactor vessel.

At some units (Forsmark 1 & 2) the insulation material on cold system components (i.e. auxiliary feedwater system, high pressure ECCS and boron injection system) has been removed. These components have an operating temperature of 50 ^{o}C or less.

At Oskarshamn 3, mineral wool was replaced by RMI at two locations due to the close presence of Minileit insulation. The reason behind this replacement is that experiments had demonstrated that a mixture of mineral wool and Minileit insulation can result in significant pressure drop across the suction strainers in the condensation pool.

The capability for manually initiated backflushing has been installed at all BWR units. At the units of the first and second generations, the backflushing media is water, while it is nitrogen at the units of the third and fourth generations.

New instrumentation has been installed at all units for measuring the differential pressure across the strainers. Such a differential pressure measurement was originally installed at some units. A "floating" alarm on high differential pressure is provided in the main control room. The actual differential pressure is compared with a curve describing the differential pressure as a function of the water flow from the low pressure ECCS. This flow is proportional to the pressure in the reactor pressure vessel.

Operating personnel has been trained in simulators to the new configuration of controls and indications, and to the practice of backflushing of the ECCS and CSS strainers.

Table 15.1: Some characteristics of the Swedish BWRs in light of the Barsebäck 2 incident.

BWR Plant **Characteristics**	**Barsebäck 2** **Oskarshamn 1 & 2** **Ringhals 1**	**Forsmark 1 & 2**	**Forsmark 3** **Oskarshamn 3**
Suction strainer areabefore modification	ECCS: 2x1m^2 CSS: 3x1m^2	ECCS & CSS combined 4x30 m^2	ECCS & CSS 4x32 m^2
Suction strainer area after modification	ECCS: 2x20 m^2 2x38 m^2 (R1) CSS: 3x15 m^2 (O1) 3x15 m^2 (B2, O2) 3x16 m^2 (R1)	No modification Performed	No modification Performed
Pipe insulation before modification	100% mineral wool	100% mineral wool	90% RMI 10% mineral wool
Pipe insulation after modification	90% RMI 10% fibreglass 100% fibreglass in mattresses (R1)	About 90% RMI 10% mineral wool	No significant modification performed
ECCS & CSS water source	Wet-well	Wet-well	Wet-well
Backflushing before modification	Yes (manually initiated)	No	No
Backflushing after modification	ECCS: 2x1 m^2 CSS: 3x1 m^2 (manually initiated on	Yes, manually initiated on differential pressure	Yes, manually initiated on differential pressure

	differential pressure alarm)	alarm	alarm
Backflush water source before modification	Wet-well		
Backflush media after modification	Wet- well water (O1, R1) Wet-well water & Desalinated water (B2, O2)	Nitrogen at 0,5 MPa	Nitrogen at 0,5 Mpa

PWRs

Ringhals 2 - 4 are 3-loop Westinghouse PWRs. In Ringhals 2 the low pressure ECCS is 2x100% and the CSS is 4x50%. In Ringhals 3 & 4 both the ECCS and the CSS are 4x50%.

At Ringhals 2, the low pressure ECCS was originally taking suction from two cage type sump screens with an area of 7 m^2 each. During the steam generator replacement in 1989, these were insulated with nuclear grade fibreglass insulation. Tests performed at that time resulted in the modification of the cage type sump screens with the installation of wire fence type pre-strainers. Furthermore an overflow was added to the original screens, based on the theory of sinking debris.

Based on the knowledge gained after the Barsebäck incident, the cage type sump screens were replaced by perforated – 3 mm holes - pipe strainers of large area, with a smaller part having cleaning possibility. The two cage type screens were accordingly replaced by four pipe strainers, one for each ECCS train and one for two CSS trains.

The main ECCS strainers have an area of 2x50 m^2 and the area of the CSS strainers is 2x40 m^2. Each self-cleaning strainer has an area of about 1,8 m^2.

The capacity of one ECCS and one CSS strainer is assessed sufficient to handle debris coming from the postulated fragmentation, during a LOCA, of all insulating material in one complete loop (in total about 45 m^3 of fibreglass and 12 m^3 of mineral wool, plus some RMI and some other debris).

The strainer modifications at Ringhals 2 were implemented during the refuelling outage 1995.

<u>References</u>:

1. Elisson, K., Bissmarck, G., Zander, K. & Svenningsson, J., “Upgrade of ECCS in Swedish BWRs – Causes and Consequences”, OECD/NEA Workshop on the Barsebäck Strainer Incident, Stockholm, January 1994.
2. Bjerke, L.-E., Vattenfall Ringhals, “Ringhals 1 – Permanent solutions”, OECD/NEA Workshop on the Barsebäck Strainer Incident, Stockholm, January 1994.
3. Bjerke, L.-E. & Henriksson, M., Vattenfall, “Modification of sump screens in Ringhals 2”, OECD/NEA International Working Group on Sump Screen Clogging, Stockholm, May 1999.
4. “Modification and backfitting at the Swedish NPPs in safety related systems”, SKI reports 95:3, 95:8, 95:23, 95:24, 95:43, 97:47 (in Swedish), 97:48 (in Swedish).

16. SWITZERLAND

Switzerland has five operating LWRs:

- Beznau I & II, PWR, Westinghouse, 2-loop design.
- Gösgen, PWR, KWU, 3-loop design.
- Leibstadt, BWR GE, Mark III containment.
- Mühleberg, BWR GE, Mark I containment.

BWRs

As a result of analyses and experiments performed by the utilities, it was established that the most valuable way to avoid strainer clogging consisted in a substantial increase of the strainer area. Area and design of the new strainers have been reviewed and approved by the Swiss Federal Nuclear Safety Inspectorate (HSK).

Subsequently, the strainers at both BWRs were replaced during the annual refuelling shutdown in 1993. Some characteristics of the new strainers are provided in table 16.1.

Table 16.1: Characteristics of ECCS strainer modifications in the Swiss BWRs.

BWR Plant	**Strainer area** before modification	after modification	**Mesh size**	**Insulation**
Mühleberg [1)]	1,3 m^2	42 m^2	2,5 x 2,5 mm	Rockwool (jacketed)
Leibstadt	6 x 2 m^2	6 x 15 m^2	2 x 2 mm	Rockwool (encapsulated)

1) One header for all pumps

Owing these modifications, clogging of strainers by insulation materials as a consequence of a LOCA causing the severe deterioration of the ECCS performance is excluded.

Another result of the modifications has been the acceptation by HSK that the earlier request for strainer backflushing is not longer necessary. This is equally valid for the previously envisaged additional monitoring of the pressure drop across the strainers.

PWRs

The review of the strainer issue for Beznau I and II demonstrated that the large strainer area and the employed insulation (RMI and NUCON™) prevent the occurrence of unacceptable pressure drops at the containment sump screens. This conclusion was, after analysis, supported by HSK.

The containment sump of Beznau I and II was redesigned in 1989 - prior to the Barsebäck event - and meets the requirements of NRC RG 1.82 Rev.1 and considers the results of NUREG 0897, Rev.1.

The review for Gösgen indicated that the sump screen design (four train safety system with four independent sumps) meets the requirements in the German regulatory guide KTA 3301 but is not in full compliance with the NRC RG 1.82, Rev.1. The main difference relates to the higher flow velocity at the screen, resulting possibly in higher pressure drops at the screen.

The strainers at Gösgen have however not been modified. In order to avoid any potential for ECCS (LPIS) pump cavitation during recirculation, a special emergency procedure has been developed covering alternative residual heat removal modes. Pump cavitation is judged unlikely unless two out of four trains are unavailable for other reasons.

References:

1. Klügel, J.-U., Gilli, R. & Voumard, A., HSK, "Measures performed in Swiss NPPs after the Barsebäck strainer incident", OECD/NEA Workshop on Strainer Problems, Stockholm, January 1994.
2. Deutschmann, H.,
3. Wand, H., E-mail communication, January 2002.

17. USA

34 BWRs and 69 PWRs are in operation in the USA. The BWRs are from General Electric with Mark I, II, or III containments. The PWRs are either from Westinghouse, Babcock and Wilcox, or Combustion Engineering design. The Westinghouse designs have either large dry, sub-atmospheric, or ice condenser containments. The Babcock and Wilcox and Combustion Engineering designs have large dry containments.

BWRs

In response to the Barsebäck event, between 1993 and 1995, the U.S. Nuclear Regulatory Commission (U.S. NRC) conducted a generic study of the vulnerability of U.S. BWRs to the loss of $NPSH_{margin}$ caused by excessive debris accumulation on suction strainers. The study included debris transport tests, debris settling tests, debris head loss tests, a single debris generation test, and various engineering analyses. The finding of the study was that loss of $NPSH_{margin}$ was very likely to occur and would occur very quickly in the typical U.S. BWR.

Between 1996 and 1999 all the BWRs took corrective actions. The corrective actions typically involved increasing the surface area of the suction strainers and establishing a schedule to remove particulate and other debris from the suppression pools. The schedule for cleaning the suppression pool was based on the rate particulate debris was generated and the capacity of the new strainers.

Prior to the implementation of corrective actions the total surface area of suction strainers ranged from 0.36 m^2 (approximate) to 39 m^2 (approximate). After the corrective actions were implemented the surface area of the total suction strainers ranged from 46 m^2 (approximate) to 580 m^2 (approximate). Most U.S. BWRs, currently, have strainers with surface areas greater than 90 m^2.

Typically, the new strainers were of one of four basic designs: Duke Engineering/ Performance Contracting Inc. stacked disk strainer, General Electric stacked disk strainer, ABB Combustion Engineering corrugated strainer, and Mark III toroidal strainer. Of the four designs, the Mark III toroidal strainer provided the largest surface area for the accumulation of debris without causing loss of $NPSH_{margin}$.

Most U.S. BWRs followed the guidance prepared by the U.S. BWR Owners Group during the development of their corrective actions. The U.S. NRC reviewed the U.S. BWR Owners Group guidance and issued a safety evaluation of the guidance.

PWRs

Between 1997 and 2001, the U.S. NRC conducted a generic study of the vulnerability of U.S. PWRs to the loss of $NPSH_{margin}$ for emergency pumps drawing suction from the containment sump. The study included debris transport tests, debris settling tests, debris generation tests, computational simulations, and various engineering analyses.

The finding of the U.S. NRC PWR sump screen blockage study was that the loss of $NPSH_{margin}$ to pumps taking suction from the sump is likely to occur in some PWRs, because of debris accumulation on sump screens following a loss-of-coolant accident.

References:

1. Zigler, G., et al., “Parametric Study of the Potential for BWR ECCS Strainer Blockage Due to LOCA Generated Debris,” NUREG/CR-6224 (SEA 93-554-06-A:1), U.S. Nuclear Regulatory Commission, Washington, DC, August 1994.
2. "Utility Resolution Guidance for ECCS Suction Strainer Blockage," NEDO-32686, Revision 0, BWROG, November 1996.
3. Safety Evaluation of Boiling Water Reactor Owners Group’s Topical Report NEDO-32686, "Utility Resolution Guidance For ECCS Suction Strainer Blockage,” USNRC, August 20, 1998.
4. Enercon Services, Entergy Operations, and FirstEnergy Corp, “Mark III ECCS Suction Strainer”, OECD/NEA International Working Group on Sump Screen Clogging, Rockville, Maryland, USA, October 1999.
5. Rao, D., et al., “GSI-191: Parametric Evaluations for Pressurized Water Reactor Recirculation Sump Performance,” LA-UR-, Los Alamos National Laboratory, Los Alamos, New Mexico, July 2001.
6. Marshall, M., E-mail-communications, July-August 2001.