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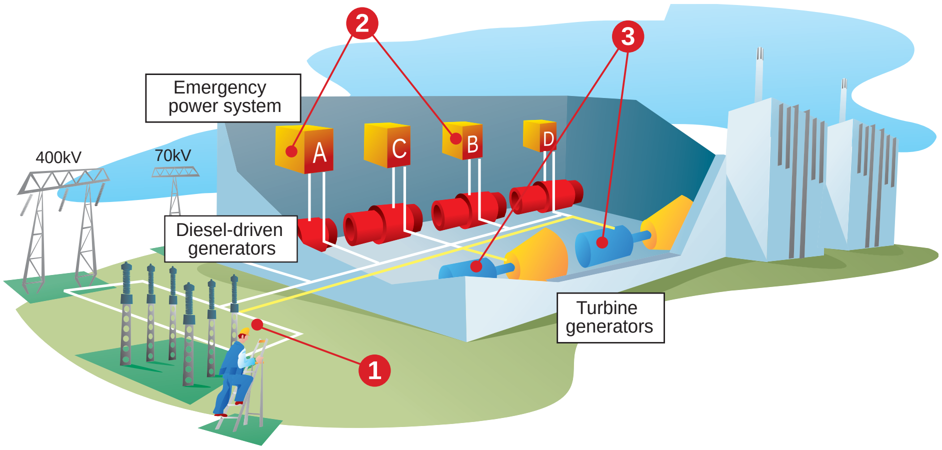
The Forsmark incident 25th July 2006



An incident occurred at 13.20 on Tuesday 25th July 2006 at Forsmark 1, which was then in operation at full power, 990 MW. The origin of the incident lay in a short circuit in the 400 kV switchyard outside the plant. It resulted in severe voltage fluctuations which, in a complicated manner, spread into several of the electrical systems in the plant.

At the time, Forsmark 2 was shut down for refuelling and maintenance. Forsmark 3 was operating at full output, but was not affected by the fault, as it is connected to another switchyard.

The voltage fluctuation resulted in Forsmark 1 (F1) being disconnected from the external grid, and the reactor being scrammed. Parts of the battery backed AC internal distribution network were knocked out, and only two of the four diesel driven generators started automatically. After 22 minutes, power was restored manually from the control room, after which the two other diesel units started. Some of the control room equipment had also been partially knocked out, with the result that, initially, the control room operators were unable to obtain a full overview of the situation.

The reactor core, however, was adequately cooled throughout the incident, and the reactor pressure vessel was not subjected to any abnormal pressure or temperature loads.

What makes the Forsmark incident serious in terms of safety is instead that the defence-in-depth reactor safety systems did not operate satisfactorily. Several safety systems that are intended to operate independently of each other failed to do so as the result of a common external fault. An important principle for reactor safety - that safety systems are designed and intended to minimise the risk of such common cause failures - was not maintained

Nevertheless, the diversity of automatically operating safety systems was sufficient to ensure that the reactor was shut down automatically and independently of the operators, and that sufficient cooling was maintained throughout the duration of the incident.

In addition, through following special incident instructions, the control room personnel were able to act in a rational manner and retain control over the situation throughout the incident. The factors that contributed to the seriousness of the situation in the Forsmark incident were as follows (see diagram above):

1. The initial event – i.e. the short circuit in the 400 kV switchyard, for which Svenska Kraftnät (the owner and operator of the Swedish national grid) is responsible – was due to the fact that work there was not carried out in the correct manner.
2. The short circuit in the switchyard resulted in a more severe disturbance to the electrical systems in the power station than the systems had been designed for.
3. Various electrical components in the power station had been replaced in 2005, but had not been adequately tested after replacement.

This report starts with a general description of reactor safety principles, followed by a presentation and analysis of the sequence of events during the incident. The principles of reactor safety have also been described in an earlier publication by the KSU Analysis Group (Reference 1). The description of the sequence of events is based on material from Forsmark Kraftgrupp AB (Reference 2), material produced by the Swedish Nuclear Power Inspectorate (SKI) (Reference 3), and on reports from individuals concerned.

Contents

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Reactor safety in principle

The three most important safety aspects associated with operation of a nuclear power reactor are:

- The chain reaction in the reactor must be controlled and, when necessary, be quickly stopped.
- The heat generated by nuclear fission in the fuel during operation must be cooled,
- The decay heat in the fuel in the core must be cooled for a considerable period of time after a reactor scram.

Further if, despite everything, a core meltdown should occur, the radioactive products must be prevented from reaching the surroundings.

Controlling the chain reaction

The chain reaction in a reactor that is in operation represents a balance between the quantity of neutrons released as a result of fission of the uranium core material, and the quantity of neutrons absorbed by the core construction material, by the cooling water and by the uranium. When operation is to be stopped, an appropriate material (usually the element, boron) is inserted into the reactor in various ways, absorbing the free neutrons.

In a Boiling Water Reactor (BWR) of the sort at Forsmark, the chain reaction can be stopped in three different ways:

- A scram, which means that a large number of control rods containing boron are inserted into the core from below by a hydraulic system, which has the effect of stopping nuclear fission after a few seconds.
- A slower shutdown procedure, which involves inserting the control rods into the core by electric motors, which takes a few minutes to achieve full insertion.
- Large quantities of boron containing water are pumped into the reactor pressure vessel.

In this incident, the first two methods operated essentially without problems. The third method needs to be used in a BWR only on very extreme occasions.

Cooling of the fuel

Fission of the uranium atoms releases energy, raising the temperature of the material and therefore of the surrounding water. This heat is conducted away as steam to the power station turbines. The steam drives the turbine rotor, after which it is cooled with sea water and returned as condensate and feed water to the reactor.

Most of the heat production by the fuel ceases as soon as the chain reaction is stopped, leaving only the decay heat.

Decay heat

It is still necessary to cool the reactor fuel for a considerable period of time after the chain reaction has stopped. This is due to the decay heat effect, which is unique to nuclear power production.

Most of the energy released by nuclear fission is in the form of heat, but a smaller amount is stored in the radioactive fission products. This decay energy is gradually released by radioactive decay, being converted to heat in the fuel.

Decay heat falls rapidly at first, so that after about an hour after a reactor scram, it is only about 1 % of the level when the reactor is in operation.

Reactor containment with filtered pressure relief

The pressure tight reactor containment constitutes a first important protection against the release of radioactivity in the (unlikely) event of a core meltdown. It was the containment that provided efficient protection for the Harrisburg Three Mile Island accident, and which was absent from the Chernobyl reactor.

In addition, for the last 15 years, the Swedish reactor containments have been fitted with filtered pressure relief systems.

These systems retain at least 99.9 % of radioisotopes released from the core, preventing them from escaping to contaminate surrounding areas, and instead containing them within the reactor containment (Reference 4).

Reactor safety in practice

Safety requires 'forgiving' systems

A fundamental condition for the design of safety systems is the understanding and acceptance that technical components and systems *can* operate incorrectly, or fail to operate at all, and that individual persons do not always act rationally.

The technical designs and the administrative systems are therefore structured so that they are forgiving of faults and errors. Important components and systems are designed with substantial safety margins, and are intended to fail safe, which means that any fault that would interfere with operation of the reactor must automatically result in a safe condition, which includes (if necessary) scramming the reactor.

There are extensive administrative quality assurance systems for designers, manufacturers, installation contractors and operating personnel, including the requirement that the safety review of all impo-tant alterations to the plant must be duplicated.

The 30 minute rule

Important safety functions are automated in order to reduce the risk of human errors. The Swedish nuclear power stations have therefore been designed in accordance with what is known as the 30 minute rule, which means that any actions or responses required within 30 minutes of an incident must be carried out automatically. The operator *can* act, but does not need to do so. The purpose of this rule is to relieve the operators from the pressure of having to act before they have had time to obtain an overall view of the incident.

Power supplies to important pumps, valves, control equipment and to the control room must be maintained at all times.

There are therefore a whole range of sources providing power to important equipment:

- From the external 400 kV grid
- From the external 70 kV regional distribution system
- From the power station's own production, known as house-load operation
- From several independent electrical distribution systems, backed up by diesel driven generators which start automatically in the event of loss of power.

In addition, there are distribution systems backed up by batteries, intended to ensure no break supply of AC power to important safety functions.

Effective in depth safety thus requires electric power to be available via several *different* types of systems, i.e. diversity. Further, the power shall come from several parallel, independent sources, i.e. redundancy.

An example of this in the Forsmark power stations is that there are four parallel diesel driven electrical generators, supplying power to separate systems, and that it is sufficient, when dealing with any type of disturbance, for two of them to be in operation in order to supply the plant with the necessary power.

In the rest of this report, the four parallel electric power supply systems are referred to as subs A, B, C and D.

Event list in brief

To the unfamiliar reader: The following text is taken from Reference 2, with only light linguistic editing. This means that some of the details may be difficult for those unfamiliar with the systems to appreciate.

The intention of the text is not to provide a wealth of detailed knowledge, but rather to give a feeling of how the sequence of events was experienced in the control room.

Time: 13:20:20 A disconnector in the 400 kV switchyard opens, creating an arc and a two phase short circuit.

+ 0 sec Both generator circuit breakers in Forsmark 1 trip on undervoltage, i.e. disconnecting the station from the 400 kV grid.

+ 0 sec Reactor output is reduced by a partial scram. Changeover to house-load operation and dumping of steam to the condenser.

+ 2 sec Rectifiers in the UPS systems (A and B subs) trip on a control fault, and the inverters in the same systems (A and B subs) trip on overvoltage.

+ 2 sec First Incident Response Checks in accordance with the Emergency Operating Procedures (EOP) initiated by the shift manager in the control room.

+ 5 sec One turbine tripped (emergency stop) due to low governing oil pressure.

+ 18 sec Changeover to direct supply of the battery backed AC network (Sub A) due to low voltage. The instrumentation chains supplied by the Sub A 220 V network were without power for two seconds, resulting (among other effects) in Channel A of the emergency stop chain tripping.

+ 24 sec The normal supply circuit-breakers to the 500 V diesel backed distribution systems open in Sub A and Sub C due to low frequency on the 500 V busbars. Instrumentation chains supplied from the Sub A network are again without power.

+ 24 sec Diesel start and connection in Sub C. Connection of Sub A fails.

+ 33 sec Emergency stop of the second turbine due to high pressure in the turbine condenser.

+ 35 sec Changeover to direct supply of the Sub A network due to low voltage. The instrumentation chains supplied by the sub B network were without power for two seconds, resulting (among other effects) in Channel B of the emergency stop chain tripping. As both the A and B channels had now tripped, this automatically resulted in a complete reactor scram.

+ 36 sec One generator circuit breaker trips on low power (less than 5 MW).

+ 36 sec Changeover to 70 kV supply to subs A and C due to low voltage in the 6 kV switchyard.

+ 37 sec The normal supply circuit breakers to the 500 V diesel backed distribution systems open in sub B and sub D due to low frequency, less than 47 Hz for more than three seconds on the 500 V busbars. Diesel start and connection to Sub D successful. Connection of diesel generator to Sub B fails.

+ 40 sec The shift manager calls for additional resources from the plant specialists and from the incoming afternoon shift.

+ 43 sec The second generator circuit breaker trips on low power.

+ 43 sec Changeover to 70 kV supply via subs B and D due to undervoltage in the 6 kV system.

+ 45 sec The first checks in accordance with the Emergency Operating Procedures are carried out by the operators. Using signals from the neutron detectors in the core, reactor output power is found to be as expected. However, there is no indication of full insertion of the control rods powered from Subs A and B.

This situation is regarded as stressful, but is recognised from simulator training of similar situations.

+ 5 min The shift manager starts systematic checks in accordance with the Emergency Operating Procedures. Falling water level in the reactor pressure vessel is noted.

+ 8 min Still no indication that all the scram control rods are inserted into the core. However, checking the readings from the neutron detectors clearly shows that the reactor is fully shut down. It is therefore considered that all control rods are actually inserted into the core.

+ 14 min Two out of four auxiliary feed water system circuits are noted as being in operation and providing sufficient cooling water flow to the reactor.

+ 15 min Falling water level in the reactor pressure vessel results in checking that at least two circuits in the emergency core cooling system are in operation.

+ 20 min First review in accordance with the Emergency Operating Procedures is completed. The shift manager calls the other operators to a quick meeting.

+ 22 min Manual restoration of power to the diesel backed 500 V Sub A busbar.

+ 22 min Manual restoration of power to the diesel backed 500 V Sub B busbar.

+ 23 min Indication that all control rods are inserted is obtained. Hot Shut Down Reactor status is verified.

+ 24 min The shift manager starts the Emergency Operating Procedures review again, as conditions have now changed, in that the diesel backed Subs A and B busbars are now energised.

+ 26 min Drive nuts of all the control rods are noted as being in the inserted position.

+ 27 min The water level in the reactor pressure vessel is noted as exceeding 3.1 m.

+ 30 min The water level in the reactor pressure vessel is noted as exceeding 4.7 m.

+ 45 min Second Emergency Operating Procedures review completed. The shift manager answers ”Yes” to the Procedures’ question ”Is the reactor safely sub critical, and is operational condition stable?”

What happened at Forsmark on 25th July 2006?

An incorrect switching operation in connection with work being carried out in the 400 kV switchyard belonging to Svenska Kraftnät outside the Forsmark nuclear power station resulted in a disconnector opening, causing an arc across the disconnector and a two phase short circuit on the 400 kV network, with resulting voltage drop.

The short circuit resulted in the two turbine generator units in Forsmark 1 being automatically disconnected from the grid, which in turn led to a brief, but substantial, overvoltage on the power station's internal electrical network.

The reactor output power was then automatically reduced to 25 % as the result of a reduction in the water inflow rate to the reactor, and because some of the control rods had been inserted. The plant therefore changed to house-load operational status, i.e. generating electricity only for the power station's own needs.

The powerful voltage variations fed through the transformers which supply the local power systems and some of the safety systems in the plant.

Each of the four subs contains an Uninterruptable Power Supply (UPS) system, as shown below. These are systems which, using batteries, en-sure a no break supply of alternating current to important safety systems.

For the UPS systems in two subs, A and B, the overvoltage resulted in failure of the units and loss of the 220 V supply. Subs C and D withstood the voltage variations and continued to operate, which meant that equipment supplied from them operated as intended.

The various integral component protection systems in the rectifiers and inverters caused two of the four UPS systems to be knocked out.

In the event of disturbances, start commands are issued automatically to the four diesel driven generators (one in each sub) that supply standby power to the power station. All the diesel generators started automatically. However, as connection of their electrical outputs to the subs is dependent on the availability of power from the no break AC system in the respective sub, two of the generators failed to connect. The two other diesel generators, in subs C and D, supplied power to the internal network throughout the entire incident.

The AC network also supplies the equipment that measures the water level and pressure in the reactor pressure vessel. This, too, is divided up into four subs. As two of the four instrumentation systems were not working, this resulted (as intended) in an automatic scram of the reactor.

Much of the instrumentation, recording and supervisory facilities in the control room were also lost, as they are supplied from subs A and B in the no break 220 V AC system.

The condensate and feed water pumps, which supply the reactor pressure vessel with water during normal operation, stopped at the same time with the reactor. The reactor was then initially cooled by dumping steam from the reactor pressure vessel to the condensation pool in the reactor enclosure, and by pumping in water via the two auxiliary feed water pumps supplied from subs C and D. This reduced the reactor pressure from 70 bar to 6 bar within 30 minutes, and the water level in the reactor pressure vessel fell to a lowest level of 1.9 m above the top of the core.

In the event of a reactor scram, all the control rods must be inserted into the core. Indication is provided in the control room when they are fully inserted, but in this case the loss of power on subs A and B meant that there was no indication for half of the control rods.

The signals indicating the control rod positions come from the electrically driven screws that insert the control rods as a backup for the fast acting hydraulic insertion. However, the neutron flux values persuaded the control room personnel that the reactor was properly shut down. The scram had operated correctly for all the control rods.

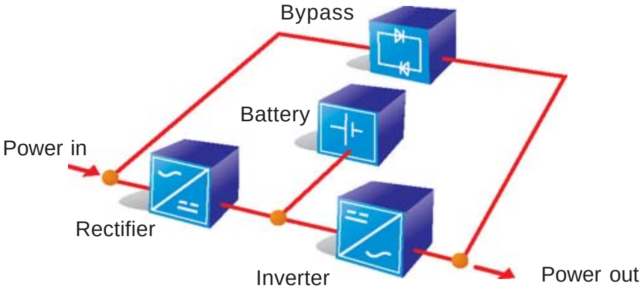
After 22 minutes, the control room manually connected the sub A and B diesel generators to their busbars, with the result that:

- Supervisory facilities in the control room were restored.
- Motor powered insertion of the control rods was completed in subs A and B, accompanied by indication that all the rods were inserted.
- Greater capacity was available for pumping water into the reactor pressure vessel, so that the normal water level was quickly restored.

After extensive checks, the control room personnel were able – 45 minutes from the initial event – to enter a brief record in the logbook that "The reactor is safely sub critical and operational status is stable".

Uninterruptable Power Supply (UPS)

The UPS systems are intended to supply the low voltage AC systems with battery backed no break power during and after a fault, for a period of at least two hours. During normal operation, the batteries in each UPS are float charged from the normal AC system via rectifiers. In the event of loss of power supply, the batteries supply the safety equipment powered from the system with low voltage AC via inverters. Both the rectifiers and the inverters incorporate various internal component protection features.



General analysis

The switchyard

In relation with maintenance activities in the 400 kV switchyard, Svenska Kraftnät (owner and operator of the switchyard), misjudged the need to interlock an earth fault protection. This resulted, during subsequent actions, in a short circuit not being timely isolated by the common bus bar protection.

Had the interlock been in place, the common bus bar protection would have isolated the short-circuit after 0.1 sec. This would have resulted in a significantly milder electrical disturbance without consequences on the emergency diesel generator backed-up bus.

Operation of the generator circuit breakers

The underfrequency protection of both turbine generators operated incorrectly. When the connection with the switchyard was interrupted, and the turbine emergency stop was triggeered, the underfrequency protection circuits of the generators should have tripped the circuit breakers when the frequency had fallen below a certain level.

New underfrequency generator protection systems had been installed in 2005. The older systems were independent of the phase sequence in the three phase grid, but the new systems are dependent on correct phase sequence.

Failure to realise this meant that testing of the systems after installation was inadequate, and did not detect the incorrect phase sequence.

If the underfrequency protection system had operated correctly, it would have meant that the diesel backed busbars would have been automatically energised.

UPS

The battery backed no break AC system is intended to supply equipment that is essential for safe shutdown of the reactor. However, in fact, this incident resulted in a loss of power from the UPS system on subs A and B.

The UPS systems were installed at Forsmark 1 and 2 over ten years ago, with trip and protection settings for the systems and components as recommended by the supplier. They replaced equipment based on mechanical technology, which was more resistant to electrical disturbances.

Tests that were carried out after the incident by the supplier of the UPS systems showed that the overvoltage protection operated as expected with voltage variations in the range 85-110 % of nominal value.

However, the voltage variation that actually occurred was much greater, and so it was to be expected that the UPS systems could not deal with it.

The fact that the UPS units in subs A and B were knocked out, while those in subs C and D were not, is probably due to small differences in the electrical circuits in the four subs, which could have resulted in the voltage fluctuations on subs C and D being less than those on subs A and B.

The diesel generators

All four diesel generator units started automatically, but the two supplying power to subs A and B failed to connect to their respective 500 V busbars as, to do this, they required auxiliary power from the no break AC systems.

This shows not only how vital the no break systems are for plant safety, but also that there were functional relationships between the distribution systems which meant that they could be knocked out by a common cause failure.

The control room

The shift team dealt with the incident in accordance with procedures that they had trained in the simulator, dealing with situations similar to that which actually occurred. This included the use of special instructions in the form of First Checks and Emergency Operating Procedures, which were applied correctly.

Despite a confusing signal situation, and loss of video screens, the control room staff carried out their work in accordance with their instructions in a particularly effective manner.

What would have happened if…?

The Forsmark Power Group and the Swedish Nuclear Power Inspectorate jointly present the following assessment.

- If more than two UPS systems and the associated diesel generator units had not worked, there would still have been a good margin against boil dry of the core and damage to the fuel.
- If three subs, rather than two, had been knocked out, the control room staff would have manually initiated forced blowdown of steam from the reactor to the reactor containment condensation pool.

It would have been possible manually to energise the three diesel backed busbars within about 20 minutes, using power from the normal station distribution system.

- If all four subs had been knocked out, it would have been possible to energise the diesel backed power systems manually from the normal power system, with sufficient time to ensure good margins against core damage.
- If none of the diesel generator units had been brought on line, and if additionally the 70 kV grid had been without power, it would have been essential for the operators to act to obtain a power supply within 40-60 minutes through manual action. A limited amount of damage could then have occurred to the fuel.
- If all four subs had been without power, *and* the operators had been unable to start correcting the situation within eight hours, it is very probable that serious damage to the core – a core meltdown – would have occurred. In this case, the various systems intended to limit the effects, in the form of the reactor containment's filtered pressure relief, would have come into play without requiring operator action. These systems would have prevented serious releases of radioactive substances to the surroundings.

This is a situation which, in terms of effects on the surrounding area, can be compared with the reactor accident at Harrisburg in 1979. In spite of a reactor core melt down the releases of radioactive substances to the surroundings were small and negligible from a health point of view.

Follow up and lessons learned

The power companies and the Nuclear Power Inspectorate

Immediately after the incident, Forsmark Power Group AB (FKA) started an in depth analysis of the incident. The results of the analysis, together with proposed actions, were presented to Nuclear Power Inspectorate (SKI) on 20th August.

SKI also started an investigation of its own, while work started at Oskarshamn and Ringhals on investigation of whether weaknesses similar to those found in Forsmark 1 were present.

SKI decided that Forsmark 2 and Oskarshamn 1 and 2 should not be allowed to start until investigations had been carried out and reported, and any necessary work carried out, as these plants contained partially similar equipment.

However, it was felt that Forsmark 3, Oskarshamn 3 and the four Ringhals blocks could be kept in operation without alterations.

OKG decided to carry out a larger modification of the Oskarshamn 1 emergency power supply system and the unit restarted in January 2007.

On 14th September, SKI decided to permit Oskarshamn 2 to restart, with similar permission for restarting Forsmark 1 and 2 on 28th September. However, this permission does also include a requirement for more long term analyses and work at the four plants.

In particular, all possible major disturbances on the external grid, and the possibility of such disturbances spreading into the plants' electrical systems, must be investigated in detail.

Shortcomings in the defence in depth concept

In its safety regulations for nuclear facilities (Reference A), SKI specifies how shortcomings in barriers and/or in the defence-in-depth concept are to be dealt with and reported. It specifies three categories of shortcomings:

- *Category 1* shortcomings are serious detected or recognised shortcomings in one or more barriers, or in the defence-in-depth concept, together with justified suspicions that safety is seriously threatened.
- *Category 2* shortcomings are less serious shortcomings in a barrier or in the defence-in-depth concept than those regarded as being Category 1, together with justified suspicions that safety is seriously threatened.
- *Category 3* shortcomings are of temporary type in the defence-in-depth concept.

In the event of occurrence of a Category 1 situation, the plant shall immediately be brought to a safe state.

Before it may be restarted without special restrictions, the investigations that have been carried out, together with any resulting work, shall have been assessed for safety, reviewed and approved by SKI.

The Forsmark incident was a Category 1 event.

Long-term follow-up and consequences

During the autumn of 2006, Forsmark carried out a critical review of the progress of the company's safety culture. It was concluded that there had been a gradual deterioration over the last few years. The company management has therefore started an extensive investigation with the aim of improving internal conditions. A comprehensive programme will be presented in the spring of 2007.

The incident resulted in the reactor being automatically shut down. When the situation had stabilised it was decided to keep the reactor at hot shut down, which is a normal procedure after a scram. The cooling down of the reactor systems to cold shutdown started about 24 hours after the incident. However, SKI regulations require that cooling down of the reactor shall start without delay following a Category 1 event (see above).

After an in-depth analysis SKI has decided that, by delaying cooling of the reactor systems, the plant operational management may not have acted in line with the fundamental requirements of the SKI regulations and the Nuclear Safety Act.

At the end of January 2007, SKI therefore passed the case to the Public Prosecutor's Office in Uppsala for a decision as to whether an offence against the Nuclear Safety Act was committed, and if the company should be prosecuted.

International

Detailed analyses of the Forsmark incident have been presented to international nuclear power organisations as IAEA, International Atomic Energy Agency, and WANO, the World Association of Nuclear Operators (Reference B).

Through them, power stations and safety authorities throughout the world can be reached with a detailed presentation of the results and experience from the Forsmark incident. For many of them, this information will result in in depth analyses and possible modifications to their reactors' safety systems.

IAEA has previously drawn up what is known as the INES scale, on which reactor incidents are classified from a safety point of view (Reference 5).

The scale runs from zero for a minor non compliance to 7 for a major accident. The lower levels (1-3) are referred to as events or incidents, and the upper levels (4-7) as accidents.

According to SKI, the Forsmark event is a Level 2 event. For comparison, the Chernobyl catastrophe was a Level 7 accident, and the core meltdown in Harrisburg was a Level 5 accident.

Since the use of the INES scale started in 1991 there have been 29 INES-1 events and six INES-2 events reported from the nuclear power programme in Sweden.

Conclusions

The Forsmark incident did not involve any damage to the fuel or reactor pressure vessel, nor to any other important components or equipment. What was serious was that the reactor's defence-in-depth arrangements did not operate entirely as intended.

An important principle in the structure of the defence-in-depth concept – namely, that no single individual malfunction can affect several different safety systems – was not maintained.

The reasons for the incident having such extensive consequences on the station's electrical and safety systems are to be found in two errors:

- *One* was that the changeover work in the switchyard was not carried out correctly, *and*
- *the other* was that the designers in their safety analysis did not assumed that internal voltage peaks could be as high as in this case because of a shortage in the external network.

Nevertheless, despite these errors, the reactor was safely shut down with a good margin, due to the fact that other parts of the defence-in-depth arrangements operated as intended.

Simulator training

In addition, the response of the personnel in Forsmark's control room showed that simulator training, together with the special instructions on actions in the event of a fault or incident, ensure that the operators work rationally even in a stressed situation. All control room personnel undergo basic training on full scale power station simulators, and then receive continuation training at least twice a year.

The simulator control rooms enable realistic exercises of very extensive fault situations to be carried out.

The Forsmark incident demonstrates the real value of training nuclear power control room operators in power station simulators. It has now been programmed into the Swedish simulators, and probably also into a number of simulators in other countries.

Loss of electricity production

The eleven nuclear power units supply in Sweden almost half of the country's electricity. The Forsmark incident on 25th July resulted in four reactors, with a total output power of about 3000 MW, being shut down for about two months.

One of them, Oskarshamn 1, with an output of about 500 MW, was shut down for over six months as a result of the incident. The four reactors together produce about one third of Sweden's nuclear power, and over 15 % of its electricity.

The weather during August and September 2006 in Sweden was warm, and the demand for electricity was low. If the incident had occurred during a cold winter, two months' shutdown of four reactors would have resulted in a need for increased imports of electricity.

It would probably not have been possible to import as much as would have been required, and so there would probably have been power shortages on the Swedish electricity system.

Author's thanks

Yngve Flodin, Vattenfall Power Consultant AB, has contributed suggestions to, and constructive criticism of, this report.

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Illustrations: ***Lasse Widlund***

References

Some reports about the Forsmark incident have been published in English by the Forsmark Nuclear Power Plant and by the Swedish Nuclear Inspectorate (Statens Kärnkraftinspektion, SKI). They can be found on the pages in English of the two home pages: www.vattenfall.se/forsmark and www.ski.se

A. The Swedish Nuclear Power Inspectorate`s Regulations concerning Safety in Nuclear Facilities, SKIFS 2004:1. The report can be downloaded from www.ski.se

B. The convention of Nuclear Safety. Background Report No 4, December 2006, Written by Lars Högberg and published by the Analysis Group of KSU. The report can be downloaded from www.analys.se

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2. ”Forsmark 1 – Störningsanalys – Bortfall 400 kV samt utebliven dieselstart i A- och B-sub”. Revision 6 daterad 2006-10-13. Rapporten finns tillgänglig på Forsmarks hemsida www.vattenfall.se/forsmark/nyhetsarkiv/Senaste Nytt/ 2006 -08-23

3. ”Granskning av FKA:s ansökan om återstart av Forsmark 1 och 2 med anledning av händelsen på Forsmark 1 den 25 juli 2006”. SKI 2006/799 daterad 2006-09-14. Rapporten finns på SKIs hemsida www.ski.se. Klicka först på ”Publicerat” och därefter på ”20060914 Beslut/Föreläggande”

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Kärnkraftsäkerhet och Utbildning AB (KSU), Nuclear Training and Safety Center

KSU is the general training and simulator training centre for the Swedish nuclear power industry. A significant part of the competence of Swedish nuclear power operators is built up and maintained by KSU's training programmes. The company also produces and administers educational material needed for its training activities.

KSU analyses operational experience from nuclear power stations all over the world and shares the results to all the Swedish nuclear power plant operators. KSU's Analysis Group provides society's decision-makers and the media with information on nuclear power safety, ionising radiation and risk assessments and comparisons between different energy sources.

Founded in 1972, the company, which is part of the Vattenfall Group, is jointly owned by Barsebäck Kraft AB, Forsmarks Kraftgrupp AB, OKG AB and Ringhals AB. KSU holds the WANO membership for the Swedish nuclear utilities and belongs to the WANO Paris region.

KSU's headquarters are situated at Studsvik, with local centres at Ringhals, Forsmark and Oskarshamn NPP´s.

The Analysis Group

The Backgrounders and Facts Series of publications are published by the Analysis Group of KSU.

The Group's main working objective is to collect and analyse data concerning points raised in the public debate on reactor safety, radiation protection, radiobiology and research into risks.

They, and other reports, can be downloaded from the Group's web site, www.analys.se which also carries links to an extensive range of national and international research organisations, nuclear power authorities and power utilities.

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