THE SWEDISH UNDERGROUND CONTAINMENT STUDIES STATE OF ART

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SUMMARY

Since May of 1973 studies of underground siting for nuclear power plants have been going on in Sweden. War protection being the primary aim in accordance with the instructions the first containment study has lead to siting in rock or in a pit. Rock siting gives better war protection than pit siting and also has less effect on the landscape, the cost being about equal.

The second study was aimed at surveying the advantages and disadvantages of a rock sited 1000 MW BWA nuclear power plant from a reactor safety standpoint, compared to a plant above ground.

Based on the instructions and considerations within the study group, the following criteria for the plant design have been established: (1) The plant should be designed to give protection against external acts of war with conventional weapons. (2) The plant should have a safety level equal to that of an above ground plant. It should fulfil the demands set by the authorities for above ground plants with respect to normal operation and accidents. No accidents that can be dealt with above ground may be permitted to result in more serious consequences, nor may they have a higher probability in a plant sited in rock. (3) The design of the plant should moreover utilize the possibilities of improving the safety afforded by rock siting.

The criterion about war protection leads to siting in rock or pit, as shown in a previous CDL study. The study group has concentrated its work on rock siting.

To clarify the other two criteria, the study group has outlined four alternative designs of a rock sited plant: (1) Reactor with complete pressure suppression (PS) containment placed together with central auxiliary equipment in a closed cavern with 48 m span that is placed about 50 m under the rock surface. (2) Reactor with complete PS containment placed together with auxiliary equipment in similar cavern as alternative 1 but open to the atmosphere. (3) Reactor placed together with central auxiliary equipment in a closed cavern constituting the containment. (4) Reactor placed in a containment directly surrounded by the rock. Auxiliary equipment placed in separate caverns.

Standardization and quality improvement today are preferred to choosing new systems and more advanced technical solutions. Also considering the desire from a safety standpoint, a rock sited plant should as much as possible exploit established technology. A consequence of the desire to use established technology is that the reactor cavern should be open to the atmosphere. If the cavern is closed, certain pipe rupture accidents may give overpressures that are difficult to master without large design alterations. The criterion about utilizing the possibilities for increasing the safety leads the interest to extreme improbable accidents, where certain advantages seem to be attainable with rock siting.

A tight, strong cavern around the reactor would thereby be an ideal solution. This design appears, however, difficult to combine with the criterion about equal safety level as above ground. This criterion that controls the safety in the circumstances normally considered for nuclear power plants must be satisfied primarily, since extreme accidents have such very low probability. The tight cavern has therefore had to stand back for the open. The study shows, however, that an open reactor cavern can also be designed to significantly increase the protection of the surroundings in extreme improbable accidents compared to above ground plants.

The chosen technical design of the reactor plant demands a cavern with a 45-50 metre span. Caverns without strengthening efforts with such spans are used in mines, but have not previously been used for industrial plants. Studies of the stability of such caverns show that a safety level is attainable corresponding to the safety required for the other parts of the nuclear power plant. The conditions are that the rock is of high quality, that necessary strengthening measures are taken and that careful studies of the rock are made before and during the blasting, and also during operation of the plant.

The third study now under way is planned to be delivered to the government in June 1977. One part in this study is going deeper in certain questions (safety, operation, maintenance, sabotage, war protection, cost and decommissioning). Another part aims to a broader view of risks and consequences in peace and war and also advantages and disadvantages of nuclear power plant for district heating.

1. Introduction

Rock siting of nuclear power plants has a long history in Sweden. When the first nuclear plant for power and district heating was proposed there was no serious discussion of other alternatives than the rock site of Ågesta near Stockholm. The construction of that plant began in 1959 and the technically successful, but costly operation lasted from 1963 to 1974. The decision of the decommissioning was taken before the oil crisis. The next step to a "half big" nuclear power plant was the R4-EVE concept, at first rock-sited in Tiveden but then going above ground in the shape of Marviken. That was around 1961.

The need for nuclear power for district heating of the bigger cities in Sweden, Stockholm and Gothenburg, gave new reasons to take up the underground alternative again. It was around 1967, 1968 ending up in a bigger study "The Swedish Study on Urban Siting" which was presented to the government in 1974 and recommended that district heat production in the metropolitan areas of Sweden should utilize nuclear heat and power plants.

Some time before that or 1973 the question was actualized from the war protection point of view. Power consumption will be lower during a war than it is in peacetime. If the proportion of nuclear power is small, the nuclear plants can be shut down. If the proportion is large, it is judged necessary to operate some nuclear units in wartime. Good protection against conventional weapons would thereby increase their endurance.

War protection being the primary aim in accordance with the instructions the first containment study has had to siting of the above ground buildings without alterations in big rock rooms or in a pit.

Rock siting gives better war protection than pit siting and also has less effect on the landscape, the cost and construction time being about equal.

The second study has aimed at surveying the advantages and disadvantages of a rock sited 1000 MW BWA nuclear power plant from a reactor safety standpoint, compared to a plant above ground. In the following this study will be related in more detail.

The third study now under way is planned to be delivered to the government in June 1977. This paper will give an overlooking picture of what is anticipated in that Study.

2. Rock siting of nuclear power plants from a reactor safety standpoint

2.1 Aims and design criteria

The general aim of this study was formulated in the instructions, to clarify the advantages and disadvantages, compared with those above ground, from the reactor safety standpoint of a nuclear unit sited in rock for war protection reasons.

To fulfil this aim it has been judged necessary to present a relatively detailed plant design as a basis for the studies and judgements.

Based on the instructions and considerations within the study group, the following criteria for the plant design have been established:

1. The plant should be designed to give protection against external acts of war with conventional weapons. It should thereby sustain the load of ten ton mine bombs.

2. The plant should have a safety level equal to that of an above ground plant. It should fulfil the demands set by the authorities for above ground plants with respect to normal operation and accidents. No accidents that can be dealt with above ground may be permitted to result in more serious consequences, nor may they have a higher probability in a plant sited in rock.

3. The design of the plant should moreover utilize the possibilities of improving the safety afforded by rock siting. This applies especially to the possibilities of better mastering extreme improbable accidents.

2.2 Choice of plant design

The criteria given in section 2.1 have governed the theoretical considerations leading to the plant design the study group has chosen to present.

The criterion about war protection leads to siting in rock, as shown in a previous CDI study.

2.2.1 Discussed alternatives

To clarify the other two criteria, the study group has outlined four alternative designs of a rock sited plant. (Fig. 1).

1. Reactor with complete containment placed together with central auxiliary equipment in a closed cavern.
2. Reactor with complete containment placed together with auxiliary equipment in a cavern open to the atmosphere.
3. Reactor placed together with central auxiliary equipment in a closed cavern constituting the containment.
4. Reactor placed in a containment directly surrounded by the rock. Auxiliary equipment placed in separate caverns.

In alternative 1 the reactor is placed in a conventional pressure suppression (PS) containment surrounded by a reactor building, placed in a cavern about 50 m under the rock surface. The cavern is made as tight as possible and strong enough to withstand loads from missiles, pressure and temperature that could occur in extreme and improbable accidents. Communication tunnels are provided with locks and penetrations that can stand the same loads as the rest of the cavern. The ventilation channels are provided with fast closing isolation valves, as is all piping that penetrates the tightening zone of the cavern. Some safety systems are placed in especially well protected spaces near the bottom of the cavern and other are placed in separate caverns outside the reactor cavern.

Alternative 2 differs from alternative 1 in that the reactor cavern communicates directly with the atmosphere through ventilation and steam relief channels connected to chimneys. The tightness demand on the rock is lower than for alternative 1, since no lasting high pressures can occur. There are no isolation valves at the rock wall in the steam and water piping. A separate steam relief channel is arranged for the part of the culvert not communicating with the turbine hall. The safety systems are arranged similarly to above ground practice. Steam relief and ventilation routes are equipped with stone beds for steam condensation and filtration of solid particles.

Alternative 3 is a variant of alternative 1, without the PS containment. Total reliance is placed on the cavern for containment. This has the character

ALTERNATIVE 1 REACTOR WITH COMPLETE CONTAINMENT PLACED TOGETHER WITH CENTRAL AUXILIARY EQUIPMENT IN A CLOSED CAVERN

ALTERNATIVE 2 REACTOR WITH COMPLETE CONTAINMENT PLACED TOGETHER WITH AUXILIARY EQUIPMENT IN A CAVERN OPEN TO THE ATMOSPHERE

ALTERNATIVE 3 REACTOR PLACED TOGETHER WITH CENTRAL AUXILIARY EQUIPMENT IN A CLOSED CAVERN CONSTITUTING THE CONTAINMENT.

ALTERNATIVE 4 REACTOR PLACED IN A CONTAINMENT DIRECTLY SURROUNDED BY THE ROCK. AUXILIARY EQUIPMENT PLACED IN SEPARATE CAVERNS

FIGURE 1. ALTERNATIVE DESIGNS OF A ROCK SITED BWR- PLANT

of a full pressure containment (dry containment) similar in principle to the containment used in PWR plants above ground, but with higher strength.

Alternative 4 has the PS containment in direct contact with the rock. The reactor hall above the containment is a part of the cavern and will be pressurized if the tightness of the containment would be lost in connection with extreme and improbable accidents.

Ventilation channels have isolation valves and the communication tunnels looks. All safety systems have been moved to separate caverns.

2.2.2 Motivations for chosen plant design

The criterion about equal safety level as above ground has been given great importance. If it is to be fulfilled in a reasonable development effort, the plant must be based on developed reactor systems and components, and on a design resembling what has been developed for above ground plants.

It is very evident today that both the power industry and the reactor manufacturers prefer standardization and quality improvement measures to choosing new systems and more advanced technical solutions. Also considering the desire from a safety standpoint, to use reliable systems a rock sited plant should as much as possible exploit established technology.

A consequence of the desire to use established technology is that the reactor cavern should be open to the atmosphere. If the cavern is closed, certain pipe rupture accidents may give overpressures that are difficult to master without large design alterations.

The criterion about utilizing the possibilities for increasing the safety leads the interest to extreme improbable accidents, where certain advantages seem to be attainable with rock siting.

A tight, strong cavern around the reactor would thereby be an ideal solution. This design appears, however, difficult to combine with the criterion about equal safety level as above ground. This criterion that controls the safety in the circumstances normally considered for nuclear power plants must be satisfied primarily, since extreme accidents have such very low probability. The tight cavern has therefore had to stand back for the open. The study shows, however, that an open reactor cavern can be designed to significantly increase the protection of the surroundings in extreme improbable accidents compared to above ground plants.

Hence the study group has judged that the formulated aims are best fulfilled by a plant with the reactor containment placed in a cavern ventilated to the atmosphere according to alternative 2. This alternative has been used for the design and evaluation of a rock sited plant here presented.

This alternative, rather than the others, keeps the same design as above ground. Accident scenarios that give small or moderate releases above ground will give similar in rock. The loads on the cavern from extreme accidents will be reduced since high pressures are relieved. All releases will with great certainty be at high altitude and be filtered through stone beds.

The chosen alternative will, as do alternatives 1 and 3, lead to a cavern with dimensions exceeding hitherto constructed caverns for industrial plants. Great

importance must therefore be laid on the possibilities to construct safe caverns.

Alternative 4 has the advantage that the span of the reactor cavern can be made with dimensions where practical experience is available. The alternative however demands significant changes in layout and system design compared to an above ground plant. The work for such new designs is judged to be very extensive. The alternative has been included in foreign studies concentrating on the rock engineering advantages. If rock siting should be practised on a large number of plants, is it possible that a design according to alternative 4 would be preferable. Pressure relief is also possible in this alternative, but has not been discussed in this study.

2.3 Plant description

The proposal made by the study group for the design of a rock sited power plant considers only one reactorturbine unit. Required spaces are in principle divided into three caverns for reactor and auxiliary systems and four caverns for turbine with equipment. The caverns are connected by communication tunnels. The caverns are oriented in the same longitudinal direction for rock mechanical reasons (Figs. 2, 3). The rock cover is some 60 metres and the plant is assumed to be sea water cooled. It is placed under the recipient level in this study. The conventional location above sea level would give some advantages, but would also strongly limit the choice of location. (Fig. 4, 5).

The reactor with connected auxiliary systems is placed, as in a corresponding above ground plant (ASEA-ATOM BWR 3000), in a building surrounded by a cavern. The cavern communicates with the atmosphere through ventilation channels and pressure relief tunnels connected to 100 m high chimneys. The cavern is strengthened and tightened to avoid ground level releases of activity.

Stone beds are placed in the pressure relief channels to the atmosphere. These condense steam and filter particles and aerosols. They are dimensioned to avoid unacceptable pressures in the cavern, even in the case of large pipe ruptures.

The rock surface is provided with concrete of sufficient thickness to keep the integrity of the cavern even when exposed to loads from missiles and pressure sequences in extreme accident scenarios. The thickness of the concrete should be around 1 metre. Locally in the ceiling of the cavern thicker concrete may be required. Penetrations for pipes and cables are missile protected, as are the locks of the transport openings. Experience from bomb shelters etc. indicates that such penetrations and locks are technically feasible.

To avoid ground water pressure behind the concrete plaster, the rock is drained by a system of drillholes about ten metres outside the rock wall. This system is supplemented by a draining system in the concrete. The draining system may also be used to take care of leaking activity, if any. The system is kept at low pressure by evacuation of air, which is controlled for activity.

A cavern on the same level as the reactor cavern floor and connected by a tunnel contains the pumps for the draining of the reactor cavern and the spray system pumps for the reactor hall.

The redundant systems for auxiliary cooling water, cavern spraying, auxiliary power switchyard and diesel generators are placed in two different caverns on each side of the reactor cavern. This gives a very good separation. One of these caverns

FIGURE 2 THEORETICAL SURFACE VIEW OF A ROCK SITED NUCLEAR POWER PLANT. (CORRESPONDING ABOVE GROUND PLANT IN UPPER RIGHT CORNER.)

FIGURE 3. PLAN VIEW ON REACTOR HALL LEVEL.

FIG. 4,5

FIGURE 4. LENGTH SECTION REACTOR - TURBINE

FIGURE 5. CROSS SECTION REACTOR - AUXILIARY SYSTEMS

contains the control room for the plant.

Between the reactor and turbine caverns runs a tunnel for steam and feed water pipes. The tunnel is connected to the containment by a culvert. Isolation valves are placed at the containment, as is the above ground praxis. In the tunnel there is a sealed off penetration. Hereby the risk for activity leaks to the turbine hall in reactor accidents is reduced. At pipe ruptures inside this seal the culvert is ventilated through a separate pressure relief tunnel. equipped with stone bed, to a chimney. In the case of pipe ruptures outside the seal the steam is ventilated through the turbine hall and its pressure relief system. This also has stone beds and is connected to chimneys. The turbine system caverns have tightened doors and penetrations that can withstand the pressures that could occur in pipe ruptures in the hall.

The turbine is equipped with extractions to heat district heating water. On both sides of the turbine cavern are caverns for feed water system and preheaters, district heating system, electric high voltage equipment, workshop, staff facilities and equipment for the treatment of active wastes.

All communications between the turbine section caverns and the reactor section caverns are provided with locks and penetrations to prevent events in the turbine section, such as pipe ruptures or fires, from affecting reactor safety. The equipment in the turbine section has no direct safety function. Reactor shutdown and decay power cooling can thus be made with sufficient redundancy without access to the turbine section.

The safety systems for a rock sited plant are in principle designed as above ground, but with some supplements. For the long time cooling after an extreme accident, for example, the reactor cavern is given a water spray system.

The ventilation of the plant is designed to give different ventilation routes for redundant systems, so that no function will be totally threatened by fire or sabotage in a single ventilation system.

Since the plant is placed below the recipient level, it has been given devices to protect from flooding. The cooling system for the turbine condensor as well as the two separate systems for auxiliary cooling are connected to their cooling water channels by siphons, which may be broken by air inlet. In the case of large ruptures in the cooling systems the siphon breaking is automatically caused by fall of level in the cooling water channels. In the case of smaller leaks the siphon effect is broken by air inlet valves initiated by level controls in the caverns.

2.4 Safety analysis

2.4.1 Normal operation

Since the releases during normal operation are small and equal between rock and above ground siting, they are not judged to affect the safety evaluation of a rock sited nuclear power plant.

The radiation level within the plant and the radioactive exposure for the staff are judged to be the same as above ground.

2.4.2 Accidents with radioactive release

The scenarios for the established design bases accidents, that is the schematic accident scenarios that are normally the design basis for the safety systems in a plant, are similar for rock siting and above ground siting. The effects on the

surroundings are in both cases slight.

A provision for this is somewhat stronger dimensioning demands on some constructions and some equipment in the rock sited plant. The background is that higher pressures and temperatures may occur in some accident scenarios due to narrower pressure relief channels. Such dimensioning is judged feasible and leads to similar accident scenarios in rock and above ground.

Extreme accidents that may lead to melted core are so improbable that measures to reduce their consequences are normally not taken for the design of nuclear power plants.

For rock siting also such accidents must be studied, if any differences in effect on the surroundings between rock and above ground siting is to be shown.

When assessing the value of these differences one must consider the very low probability of these accidents.

The principal advantage of rock siting is the greater resistance of the reactor cavern against pressure and temperature loads than is possible to attain with reasonable efforts above ground. It is therefore possible with great certainty to conduct releases from extreme improbable accidents through stone beds to chimneys for releases at high altitudes. The stone beds have filtering effects on iodine and suspended particles, and reduce the flow by condensation of the steam.

It is therefore judged probable that released activity quantities are considerably lower, except for noble gases, in such extreme accidents in a rock sited plant, than in an above ground plant. The release is also spread out over a longer period of time, say one day instead of one hour.

The risk for activity releases being spread through the ground water is low, as it is for above ground plants. This is because the ground water flow is directed towards the plant. Collected ground water can be controlled for activity before release.

2.4.3 Fires

The probability for fires is judged to be the same as above ground. The damage may however be worse, since the possibilities for ventilation directly to atmosphere are smaller. The amount of inflammable matter indoors is greater in the rock sited alternative, since diesel tanks, oil-filled transformers etc. are placed in tunnels and caverns, but these risks are compensated by extended fire fighting equipment and suitable design of the ventilation systems. There will however be larger problems for manual fire fighting in the rock sited alternative. All ventilation of smoke fumes after a fire must go through the ventilation systems.

Fires must thus be considered to be more difficult to master in rock than above ground. Design measures can however be taken to reduce their effects on the safety. Rock siting is then judged equal to above ground siting in this respect.

2.4.4 The integrity of the cavern

A large portion of the work in the study group has been directed towards identifying the factors determining the stability of the rock. This is especially necessary since the reactor cavern will be larger than previously blasted caverns for installation purposes.

Based on this work, the study group judges it technically possible to con-

struct reactor caverns with 45-50 m spans in many places in Swedish rock, and with a stability restricting the risks of falling rock to a sufficiently low level.

This judgement presumes

- that the preliminary investigations of the rock are made very extensive and thorough
- that the quality of the rock expressed in a five grade scale is of the highest or next to highest grade, which means that unfavourably placed clay and cross zones are not present
- that the rock cover exceeds 40 metres
- that rock mechanical measurements, such as deformation, microseismic and bolt strain measurements, are made in the reactor cavern during blasting, construction and even during operation of the plant
- that extensive calculations are made with the parameter combinations the rock has at chosen location,

Theoretical calculations of the stability of caverns have been made also for rock masses with very unfavourable structures. The calculations are made using the finite element method and include strengthening measures on the rock, such as bolting and shotcrete. The calculations show that under these unfavourable conditions it would also be possible to give a cavern satisfactory stability at spans of 45-50 metres. That is if a suitable shape is used and appropriate strengthening measures are taken.

A study conducted about the occurrence of caverns with large spans seems to support the theoretical calculations. Mining technology shows several examples of caverns with spans of this size, that have been stable without any especially extensive reinforcements.

The study group presents a model that shows how the stability of the cavern can be indicated at different steps as a project comes along. The basic elements in this model are calculations based on extensive field investigations and measurements during the construction of the caverns.

2.4.5 Flooding

A plant sited in rock below the recipient and ground water levels is subject to the risk of flooding. This applies mostly to the turbine hall in a cooling water pipe rupture. Systems that could cause flooding have therefore been given special shut-off devices, such as siphons with air inlet valves etc. Some caverns are also designed to hold substantial amounts of water without jeopardizing the safety of the plant. Doors and locks that can withstand some flooding, and also overpressure in the case of steam releases, are introduced. For the long time draining of leaking ground water there are draining pumps with redundancy. The proposed measures, possibly with some supplements, should make it possible sufficiently to reduce the risk of flooding.

2.4.6 Sabotage and acts of war

The risk of sabotage, with consequences to the safety, by someone unauthorized entering the plant is judged to be somewhat lower for a rock sited plant than above ground. This is due to the more complete separation with doors and locks. Moreover, it should be more difficult to enter the rock sited plant, since there are only a few accesses.

The risk of safety consequences from sabotage from the outside, acts of war

crashing aircraft, explosions on the outside etc. is judged to be considerably lower for the rock sited plant. The communications with ground level must however be given shock wave pockets etc. and be supervised.

Special protection is required at intake and outlet of cooling water, so that they cannot be blocked. Tunnels, screen chamber, and pump rooms in caverns at recipient level may have to be reinforced against ejection in the case of bombing.

The plant is so designed that the demolition of chimneys in a bomb attack will not constitute a threat to safety. There will be a risk of activity release at ground level in a subsequent accident but this should be of subordinate interest in a state of war.

Natural disasters, hurricanes and earthquakes.

Hurricanes, floodwaves and tornados are judged to have less safety effects on rock sited plants than on plants sited above ground.

A rock sited plant can more easily be designed to withstand the seismic loads of an earthquake. This is due to the deeper position, and to that the buildings may be secured to the rock against excessive deformations. The risk for falling rock is judged to increase only if the epicentre of the earthquake is in the immediate vicinity of the plant.

2.4.7 Effects on the surroundings

The effects on the surroundings from normal operation show no difference between rock and above ground siting.

The releases in accident scenarios of the kinds that normally form the basis for designing nuclear power plants are judged to be equally small for rock siting as for above ground siting. No higher probability for accidents can be expected with the design demands that have been put on the rock sited plant.

In extreme improbable accidents leading to core melt-down the releases are judged to be reduced, made at higher altitude and over a longer period of time at a rock sited plant. A total reduction of the potential doses in the surroundings by a factor of 10 seems realistic.

2.5 Time schedule and costs

A comparative study of the time schedule has been made to assess the difference in construction time between a rock sited and an above ground sited nuclear power plant. In both cases the first unit at a new site has been studied. The schedule shows that the locating permit for a rock site should be applied for 10 years before operation. Reactor and turbine equipment should be ordered 8 1/2 years in advance. The corresponding times for an above ground plant are 8 1/2 and 7 years respectively. This means a prolongation for the rock sited plant of 1 1/2 years.

The extra costs for rock siting of a nuclear power plant, have been calculated and compared to an above ground BWR 3000 plant. The technical treatment is naturally not so detailed as for the above ground plant, which affects the accuracy of the economic assessments.

On the construction side the increased costs are mostly caused by rock work. Except for the costs for blasting the caverns, the costs for tunnels and strengthening measures weigh heavily.

Increased costs for electric and thermal equipment are chiefly due to higher

installation costs and changes in the system design to adapt it to rock siting. The layout with several separate caverns requires longer pipes and cables for many systems. The siting below recipient level makes it necessary to change the design of the cooling system including the turbine condensor. Capsuled switchyards are also required in rock siting.

Due to the longer construction and installation period engineering and administration costs will rise. The extra cost for interest during construction has been computed using a 10 % calculation interest. The interest share of the total extra cost is about 40 %.

The result of the cost calculation shows that the extra cost for rock siting represent an increase of 15 & 20 % compared to above ground siting.

Operation and maintenance costs increase in rock siting due to increased staff and increased needs for local power. Rock siting could also lead to decreased accessibility due to more difficult communications between the different parts of the plant. The increased variable costs are however subordinate to the increase in investment costs in the total economy of the plant.

2.6 Concluding commentaries

The study has aimed at surveying the advantages and disadvantages of a rock sited nuclear power plant from a reactor safety standpoint, compared to a plant above ground.

The studies performed are almost entirely concentrated on the BWR alternative. The reason is that the studies and modifications that under all circumstances must be made to carry through a rock siting of a nuclear power plant are made easier by cooperation with a domestic reactor contractor. This seems at least to be the case at present, since foreign power companies and reactor builders are not seriously considering rock siting of nuclear power plants.

The study group has developed general criteria for designing a nuclear power plant in rock. Based on these criteria, alternative theoretical plant designs have been studied.

The design judged most appropriate has been studied in greater detail, and a relatively extensive safety analysis has been made. The study group has found that the presented technical design of the rock sited alternative is sufficiently advanced to form a basis for further projecting treatment.

The chosen technical design of the reactor plant demands a cavern with a 45-50 metre span. Caverns without strengthening efforts with such spans are used in mines, but have not previously been used for industrial plants.

Studies of the stability of such caverns show that a safety level is attainable corresponding to the safety required for the other parts of the nuclear power plant. The conditions are that the rock is of high quality, that necessary strengthening measures are taken and that careful studies of the rock are made before and during the blasting, and also during operation of the plant.

A superficial judgement may give the impression that considerable safety advantages are gained by rock siting. It is possible to gain some safety advantages by rock siting, but these mostly take into account the environmental consequences of extreme, very improbable accidents. For the accidents that are normally considered in designing nuclear power plants - which are also very improbable - one cannot correspondingly

count on a further improvement of the safety. In addition to the advantage of protection against war action and other external impacts, rock siting may also give advantages in restoration after termination of operation.

The presented rock sited nuclear power plant has been assessed to cost 15 & 20 % more in total construction costs than a corresponding above ground plant. A large portion of the increase depends on interest during construction, due to the 1 1/2 year longer construction time. Also operation and maintenance costs are somewhat increased by rock siting.

Whether these extra costs are justified or not depends on how the values of the advantages are assessed. Especially the judgements of the safety aspects depend on the choice of location. The motivations for rock siting also depend on whether a condensing plant for only electricity production, or a plant for combined power production and district heating, is considered. The latter would under certain circumstances make rock siting look more attractive.

2.7 The Study Group

Members of the study group appointed by the Board of CDL (a joint organization of major Swedish power producers):

Ingvar Wivstad (Chairman)	)	
Tord Lindbo	)	The Swedish State Power Board
Håkan Johansson	)	
Ebbe Forsgren	)	
Emil Bachofner		Oskarshamn Power Group, OKG.
Rune Overup		The South Swedish Power Co. Ltd.
Per Almqvist		Energy Supply Authority of Stockholm

Additional contributions to the Study from:

Swedish Nuclear Power Inspectorate, Atomic Energy Company of Sweden, Vattenbyggnadsbyrån AB - VBB, AB Asea-Atom and The Swedish State Power Board.

3. UBK Study - Underground Siting of Nuclear Power Plants (preliminary)

3.1 Instructions from the government to the SSPB for further study of rock siting of nuclear power

In 1975 the Parliament demanded that before decisions of new sites the possibilities of underground siting would be made clear. As earlier Studies made by CDL were judged to be not sufficient as ground for a decision the government ordered the SSPB to accomplish necessary complementary Studies before June 30, 1977.

3.2 Possible safety development of above ground nuclear power plants

When comparing advantages and disadvantages with underground siting for modern LWR is it necessary to look over alternative developments of the safety of above ground plants. In order to do that extreme reactor accidents (core melt) and protection against external loads seems to be of most interest. However, there is difficult to see changes in the technical design of today which could reduce the risk for core melt. On the other hand, measures that will reduce the consequences for the environment may be thinkable, e.g. containment with relief channels through filters to chimneys. Another measure would be concrete protection against external missiles of different kinds including war protection to a certain degree. However, these measures for increasing the safety of above ground plants are very costly and must be weighed against the degree of effect in

each case and the very low probability of the accident.

3.3 The design of the underground nuclear power plant

The chosen alternative of the CDL Study of 1975 has been further studied. It is true that this alternative was costly but the conclusion must be the same because of the very extensive work for another design. If the desire is to increase the safety many people judge that new design principles are inconvenient. A reactor manufacturer could also be unwilling to put in development resources for one single plant without any market for other sales.

The turbine design has been studied in detail with lines for extraction of heat for the district heating water, the heat condensers and the cooling water systems. The fire problems and the problems with explosions in oil mist from leaking transformers and diesel plants has also been studied.

3.4 The necessity of nuclear power production in war

With the weapon system of today there is not very difficult to damage above ground nuclear plants ^{in operation} in such a degree that extreme accidents would occur. But, on the other hand the risk and the consequences from this is probably not more difficult than from other military attacks against metropolitan centers or chemical industry.

The want of power in wartime is essentially lower than in peace and therefore the war power supply in Sweden for the next decade possibly could be produced with other sources than nuclear. How it would be for the decade after that is not very clear today depending on the development of energy saving, specially power saving, and also development of alternative energy sources.

3.5 Differences between underground and above ground nuclear power plants with regard to the risk of release of radioactivity

For extreme accidents the CDL75 Study showed that the radioactivity dose to environment was one tenth underground compared to above ground plant. Research on the filtering effects of the stone bed has been going on and the results will be available in May 1977.

For the more thinkable design accidents the CDL75 Study showed no difference in release to the environment. But for smaller accidents that cause no harm at all to the environment the underground design with respect to fires, oil mist explosions etc. could possibly turn up with a slightly higher frequency of shut downs and start ups. As reactor accidents mostly occur when shutting down and starting up the conclusion is that the safety will be slightly lower underground.

3.6 Decommissioning after terminated operation

SSPB has joined a study of decommissioning within Unipede which is going on now. From that study work ^{French study} is reported that decommissioning of a 900 MW PWR plant was calculated to cost 4-8 % of the original investment when doing it directly after the operations was terminated. When waiting some 30-40 years the cost was only 2-4 %. The study also follows what is going on in the US and England.

However decommissioning of an underground plant is essentially easier than above ground. The cost is also lower about half of that above ground.

3.7 Underground siting of nuclear power and district heating plants

Underground siting of nuclear power and district heating plants would be more economically than units for only power production if the underground alternative

would give the possibility of locating near the district which is to be supplied with heat. Then reduced heat water lines would balance the extra cost of underground siting. For the urban site, the underground plant, could be tolerable as the influence on environment is less than on the more distant above ground plant and also the consequences of extreme accident is reduced which is much desirable near bigger populated areas.

If only the last mentioned safety aspects is to be considered the radioactivity release is the same for an underground plant sited 25 km from the metropolitan center as for an above ground plant 80 km away. It also happens that by supplying 2000 MW heat the extra cost for undergrounding balances the 50 km longer lines to the above ground plant.

An advantage for the urban underground plant is the value in wartime of protected power production in an urban area with short power and heat water lines.

3.8 Cost analysis and conclusions

As already said, the UBK Study will be finished in June 1977 and this is written in March. From this reason it is not possible to formulate any conclusions and the cost analysis is not yet made. It is also advisable to stress very strongly that the whole section 3 of this paper reflects only a draft of the future UBK report.

3.9 The UBK Study organization

The responsibility of the UBK Study lies entirely on the Swedish State Power Board and is performed of the Boards organization under leadership of Ingvar Wivstad and with a working group. Contributions from other enterprises come from Asea-Atom, Stal-Laval and Atomic Energy Company of Sweden.

References

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 Standpoint - CDL 1975
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