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Underground Siting of Nuclear Power Plants

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1. Zusammenfassung

Es wurden zwei Möglichkeiten der unterirdischen Anordnung eines Kernkraftwerkes, die Anordnung in Felskavernen und diejenige in Lockermaterial am Beispiel zweier typischer schweizerischer Standorte untersucht.
Anhand der vorgeschlagenen Anlagedispositionen wurde weiterhin der Einfluss der unterirdischen Anordnung auf das Betriebsverhalten sowie auf das Verhalten bei Störfällen der Anlage untersucht.

2. Resumé

Deux variantes de centrale nucléaire souterraine ont été étudiées: la disposition en cavernes rocheuses et la disposition dans du terrain meuble. Deux sites typiques pour la Suisse ont été considerés.
On a examiné pour ces deux variantes l'influence des dispositions souterraines choisies sur le comportement opérationel ainsi que sur le comportement en régime d'accident.

3. Abstract

Two of the main underground siting alternatives, the rock cavity plant and the pit siting, have been investigated in detail and two layouts, developed for specific sites, have been proposed.
The influence of this type of siting on normal operating conditions and during abnormal occurences have been investigated.

1. Introduction

The Swiss Federal Institute for Reactor Research has performed since 1975, in collaboration with the Federal Institute of Technology and some engineering consultant companies, various studies of different alternatives of the underground siting of nuclear power plants. The aim of these studies has been to investigate aspects such as constructional feasibility, safety potential, concept alternatives and cost of this type of siting.

Two of the main underground siting alternatives have been investigated:

- plant in excavated rock cavities
- plant in open cut excavation

For both siting alternatives a specific site has been chosen as example. For these studies a three loop Westinghouse 3000 MWth NSSS has been taken as reference plant.

2. The rock cavity alternative

The aim of the study of the rock cavity plant was to establish the feasibility of the concept, mainly from the civil engineering point of view. Since plant protection against acts of war and plant operation during conventional warfare were assumed as design criteria, all vital areas of the plant have been located underground in excavated rock caverns.

For this first investigation a specific site in the Swiss Alps, with known rock characteristics, has been chosen as example. The rock quality at the site can be defined as good (SIA class I or II).

The plant layout is shown in fig. 1.

The nuclear steam supply system is located in a single cavern, cylindrical in shape. The containment system of the reference plant with a double containment has been maintained in the underground location. A free standing steel shell, with dimensions similar to those of the corresponding above ground plant, performs the functions of the primary enclosure while the cavern rock wall, lined with concrete, acts as the secondary containment. A steel shell was preferred to a prestressed concrete structure as a primary containment mainly because it requires

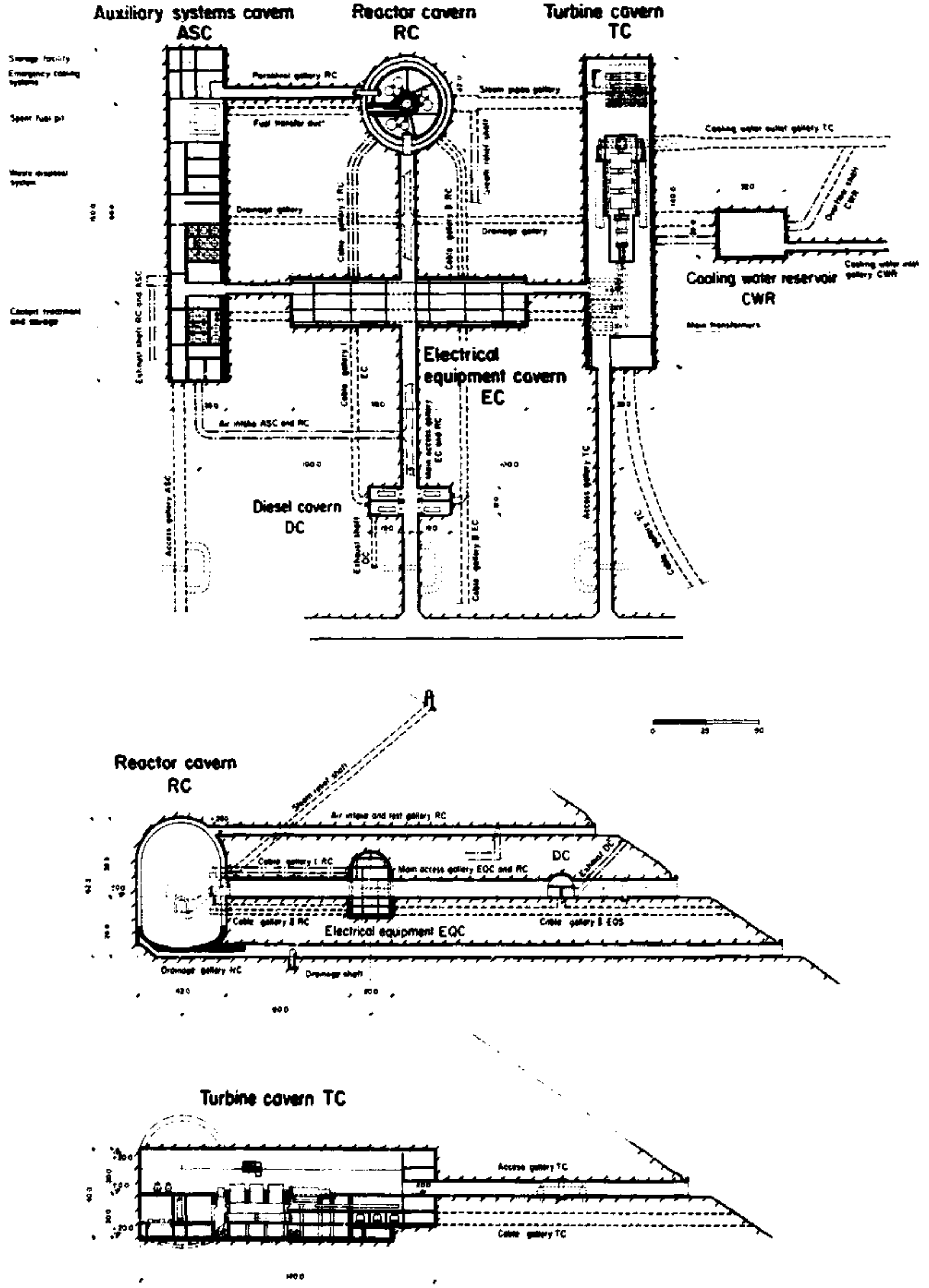

Fig. 1 The rock cavity plant layout

a smaller cavern diameter and because of an easier construction. The remaining plant components, i.e. the reactor auxiliary systems, the fuel handling systems, the electrical equipment and the main turbine are located in three large horse-shoe shaped, elongated caverns. The position of the caverns relative to the reactor cavern is similar to the position of the corresponding buildings in an above-ground plant, with the difference that, due to rock stability considerations, the distance between the different caverns is larger than the distance between the corresponding buildings in an above-ground plant.

The reactor cavern with an excavation span of 42 m, exceeds the experience acquired till now on man-made caverns and has therefore been subjected to a preliminary investigation of the rock static behaviour. This analysis has shown that the deformations of the rock walls both during and after the excavation, mainly as a consequence of the rock quality and of the rotational symmetry of the cavern shape, remain within acceptable limits. The span of the other caverns is similar to that of already existing underground cavities and therefore is not expected to pose any structural problem.

The chosen layout is of particular advantage during the plant construction; in fact, every large cavern has its own access to allow a simultaneous excavation process. Most of the excavation tunnels can be used, after completion of the plant, as part of the ventilation or of the drainage system.

The material access tunnels have been dimensioned for the size of the largest component to be transported during construction or operation of the plant (e.g. the material access tunnel to the reactor cavern was dimensioned for the steam generator). For personnel, a net of tunnels connecting the four caverns at the same operating level has been provided for.

3. The pit siting alternative

This underground siting alternative, also called "cut and cover" or "cut and fill", consists in building the plant in an open cut excavation, both in rock and in soil, and then in covering the structures with the excavated material and/or special material.

After a preliminary investigation of the technical feasibility of this siting concept, based on a plant entirely located underground, a detailed study of the pit siting alternative has been carried out.

The main purpose of locating the plant underground is to provide additional protection to the public and to the environment in case of major hypotetical accidents (Class 9) and to the plant against external events, including aircraft crashes and sabotage. As a consequence of these requirements and since the plant is not required to operate during war time, only the nuclear island is located underground.

A specific plant site has been chosen in such a way as to represent typical topographical and geotechnical conditions of the Swiss plateau, i.e. a moraine layer of variable thickness covering a molasse bedrock. Therefore, the underground plant is partly in rock and partly in soil.

The reference plant has been followed as closely as possible to ensure safety against Class 1-8 events. Only minor changes have been allowed as, for instance, the replacement, based on constructional reasons, of the prestressed concrete primary containment of the reference plant by a steel containment. Moreover, since the plant should fulfil the requirements of the safety authorities, a "Notstand" system has been included in the underground plant design.

In the underground portion of the plant, the fuel handling building, the auxiliary building, the steam and feed cells and the Notstand building are arranged in a compact structure around the reactor containment.

About 12 m of backfill cover both the nuclear island and the accesses. This cover thickness is considered sufficient to protect the underground structures against external events and to ensure, with the exception of the noble gases, a complete fission products filtration following a major hypothetical accident.
The plant depth of burial is chosen in such a way as to minimize the problem of the excavation débris utilizing a large part of them for the backfill and to avoid, at the same time, too large earth loads

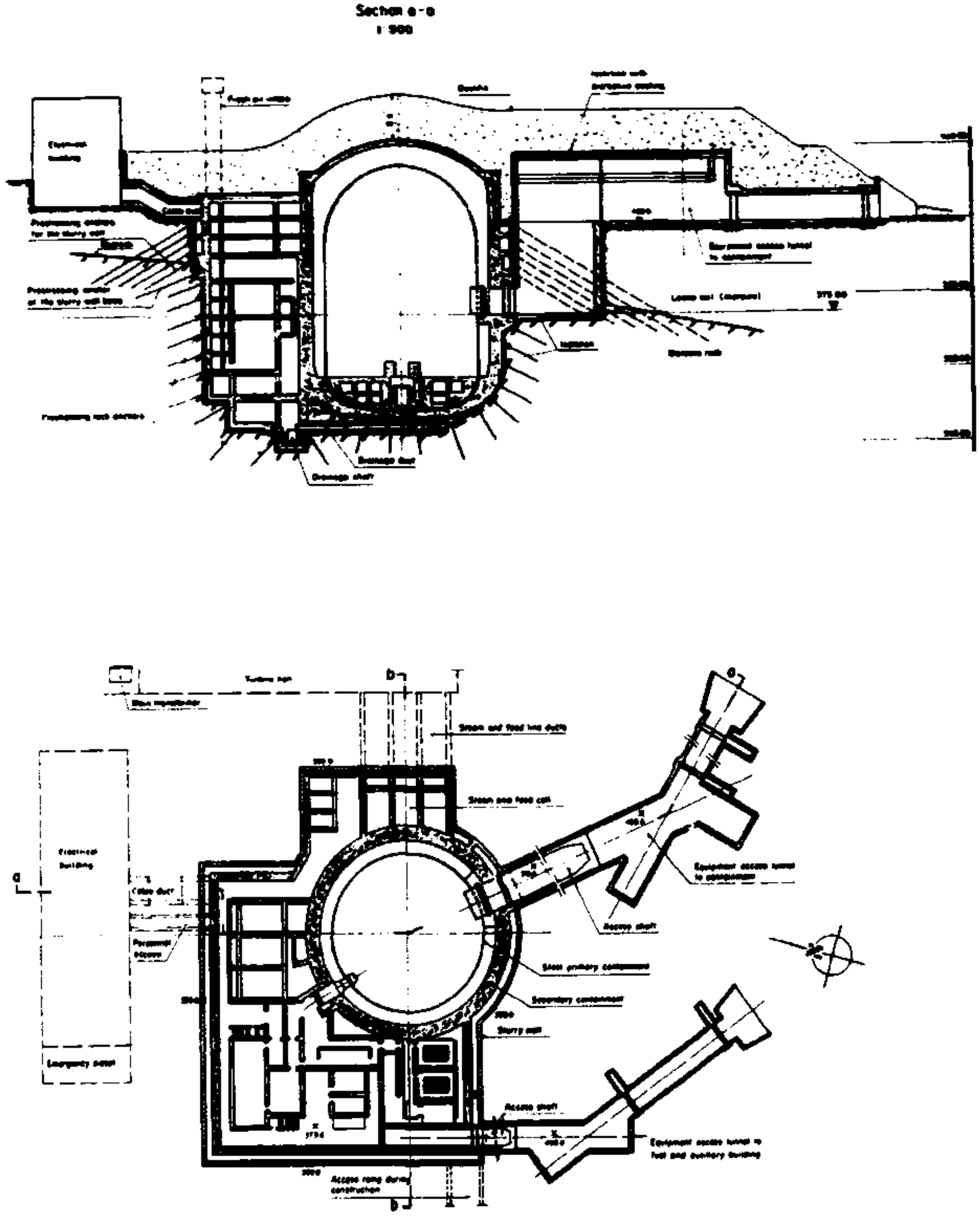

Fig. 2 The pit siting plant layout

on structures with large internal openings (as the fuel handling building) by locating them in rock.

A containment system based on the pressure relief concept has been proposed in this study. In case of an accident that causes a loss of integrity of the primary containment, while the underground portion of the plant is undergoing pressurization, the containment is vented via an iodine filter to the stack so that the pressure will not rise above the penetrations design pressure. All possible leakages past penetrations seals, airlocks etc, will be collected through a second low pressure barrier by means of an exhaust system that will keep the interspaces below atmospheric pressure. This system will then pass the leakages through an iodine filter to the stack.
In this way, the risk of penetrations failure followed by sudden unfiltered ground level releases can be considerably reduced.

4. Safety considerations

To avoid introducing too many uncertainties in the safety evaluation of the underground siting the reference design has been followed as closely as possible, in both siting alternatives, limiting to a minimum possible departures from the reference plant.
However, because of the inherent characteristics of this type of siting, the proposed underground layouts are quite different from that of the surface reference plant. These differences, in the case of the rock cavity alternative, are mainly due to an "expansion" of the plant layout and to the fact that the rock surrounds completely every part of the plant itself. In the case of the pit siting, the nuclear island is somehow more compact than in the reference plant and is completely surrounded by earth and rock.

The influence of these differences on the overall plant safety is not very relevant for events up to the DBA. For instance, since systems, components and layout of the reactor building are the same as in the reference plant and since also the same containment system with a double containment, has been maintained for the underground layout, safety during normal operation should not be significantly affected by the underground siting. Moreover, also the probability of design basis events occuring should be considered the same as for a surface plant.

Accident scenarios, for events occurring inside the reactor containment, up to Class 8, are the same as above ground.
Variations of accident scenarios could instead be expected, especially for a rock cavity plant, for accidents occurring outside the reactor containment. These variations are mainly due to pressure build-ups and/or temperature rises in some plant areas as a consequence of steam pipes ruptures, fires etc.
If the accident scenarios outside the containment are the same as in the reference plant, no significant differences are expected.

The influence of the underground siting on the plant safety is more remarkable in case of extreme hypothetical accidents, as Class 9, and in case of external occurrences.
In case of extreme hypothetical accidents, the medium in which the plant is located can be considered as an additional barrier against radioactive releases mainly basing on the following considerations:

- the resistance of an underground containment to extreme loading conditions (temperature, pressure, missiles etc) is, because of the rock or soil overburden, by far greater than any that can be reasonably achieved in a surface plant.

- in the case of a containment failure, the release will be into the medium and not directly to the atmosphere.
  The leakage will therefore be controlled and reduced by the permeability and porosity of the medium, by groundwater pressure, by plateout effects, by absorption, ion-exchange reactions, etc.

- once that the driving pressure caused by the accident has been suppressed, the leakage flow will be reversed towards the reactor building.

However, since the preferential path for a radioactive release from the containment is not into the surrounding medium but towards other plant areas, the potential additional containment level of the underground siting is largely dependent on a reliable sealing of penetra-

tions and accesses.
Tests with underground explosions of nuclear weapons have shown that leakfree penetrations and valves can be provided for temperatures and pressures (and especially peak pressures) by far exceeding those which can be expected to occur in a nuclear power plant. Nevertheless, also in case of penetrations failure it should be noted that:

- the start of the release to the atmosphere will be delayed for a few hours while tunnels, ducts etc are undergoing pressurization that later could cause failure of outer seals.
- a reduction of the radioactive release can be expected because of the longer path to the atmosphere, of filtering effects through the penetrations, of plateout effects, of natural decay etc.
- a reduction of the consequences for the public can also be expected because of the longer time available for the implementation of emergency measures as population alarming, evacuation etc.

Of course, active measures such as containment depressurization systems with expansion chambers or pressure relief circuits as that previously briefly described (§ 3) can be taken to minimize the danger of penetrations seals failures.

The underground location, because of the rock or backfill, provides a better protection against low probability external events, both natural and man related. Immunity to surface phenomena such as storms, aircraft crashes, explosions etc can be easily achieved while mitigating the effects of other external events, such as earthquakes, sabotages etc. Very important is also the inherent capability of underground plants to withstand the effects of conventional warfare.

For the alternative in rock, a new type of accident to which the plant may be exposed because of the underground siting is a rock fall.
The consequences of a rock fall, if safety components are damaged, are considered to be comparable to those of a safety system failure. It is impossible to give evidence in advance that, in a given medium a

cavity can be built to any specific safety requirement. However, the general consensus is that, in competent medium, rock falls should not occur after reinforcing work has been completed.
No new type of accident initiating event, because of the underground siting, has been instead identified for the alternative in soil or pit siting.

An investigation based on the proposed layouts has shown that events such as fires or flooding can be easily handled without requiring extensive modifications of the conventional safeguard systems.

5. Concluding remarks

Two possible variations of the underground siting concept, the rock cavity plant and the pit siting, have been investigated in some detail and two specific layouts, based on a Westinghouse PWR, have been proposed.
A first safety analysis, based on the proposed layouts, has been performed. It shows that the underground siting of nuclear power plants offers potential safety advantages as the additional level of containment in case of extreme accidents or the improved protection against external events including acts of war and sabotage.
Moreover, it shows that from the safety point of view, neither of the considered alternatives has substantial advantages on the other.

It should be, however, noted that in both alternatives, as also in other studies on the subject, the underground portion of the plant is, besides minor differences, nothing else than a duplicate of a surface plant. Therefore, if substantial safety advantages are pursued with the underground siting, a new nuclear power plant concept, capable of entirely exploiting the possibilities offered by the siting should be developed instead of burying a conventional surface nuclear power plant .