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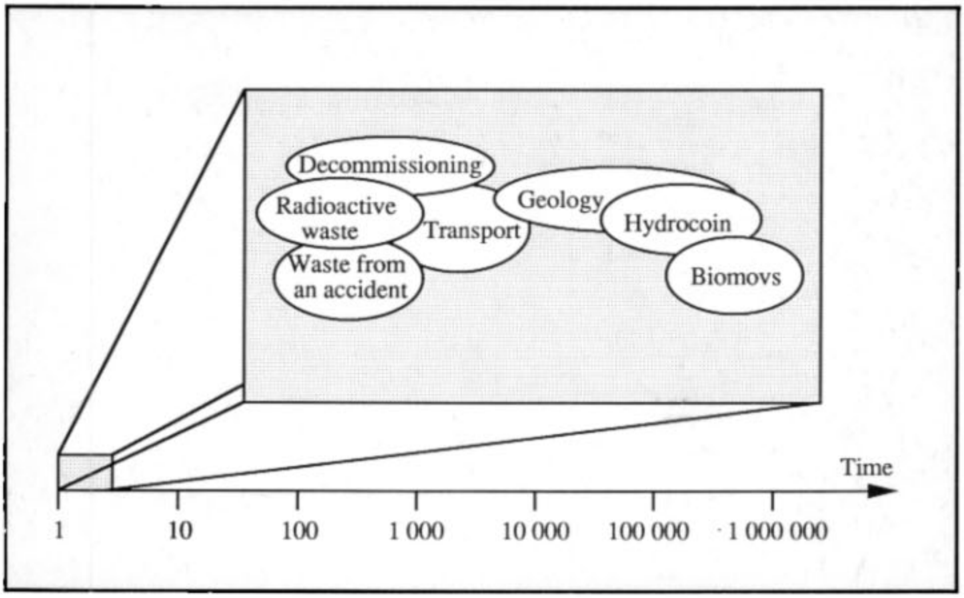
ASPECTS OF NUCLEAR WASTE MANAGEMENT

AFTER A 4-YEAR NORDIC PROGRAMME



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ASPECTS OF NUCLEAR WASTE MANAGEMENT

AFTER A 4-YEAR NORDIC PROGRAMME

Summary Report of NKA/KAV-Projects

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ABSTRACT

Six areas of concern in nuclear waste management have been dealt with in a four-year Nordic research programme. They include work in two international projects, Hydrocoin dealing with modelling of groundwater flow in crystalline rock, and Biomovs, concerned with biosphere models. Geologic questions of importance to the prediction of future behaviour are examined. Waste quantities from the decommissioning of nuclear power stations are estimated, and total amounts of waste to be transported in the Nordic countries are evaluated. Waste amounts from a hypothetical reactor accident are also calculated.

Key words: coordinated research programs, probabilistic estimation, radioactive wastes, reviews, Scandinavia, waste management.

SUMMARY

Nuclear waste management includes a variety of questions related to a number of different scientific disciplines. It also comprises time perspectives which have not been discussed earlier in connection with environmental pollution. R&D in this field is well suited for international cooperation and has been the subject of joint Nordic project work for several years. This cooperation is part of a larger cooperation in the field of nuclear safety which was initiated by the Nordic Liaison Committe for Atomic Energy, NKA.

The topics dealt with in the latest programme period (1985-1989) are not specific for the Nordic countries but they reflect the high ambitions on nuclear waste management in these countries. Final reports of the programme (abbreviated KAV) have been presented during the spring 1990.

Finland and Sweden have nuclear power plants in operation, but many of the questions studied in the joint programme are relevant to research reactors and accordingly of interest also for Denmark and Norway. Among these questions is the fact that eventually all nuclear reactors will be decommissioned, and that transport of radioactive material is taking place in all the Nordic countries. Thus, it has been possible to study the decommissioning of a Norwegian research reactor, and to estimate the need for transports of radioactive material in the Nordic countries in relation to existing regulations. It has also been possible to develop a joint proposal for quality assurance of transport containers.

Some of the projects have an interest primarily for authorities and industry in countries with nuclear power reactors. A typical example is how to cope with the situation in case a relatively large damage should occur to the reactor core, and how to handle the waste that will be produced.

The international Hydrocoin project, the purpose of which is to increase the understanding of groundwater movement in crystalline rock, is primarily of interest for those countries where spent fuel and highly radioactive waste is to be disposed of in underground repositories. The project has led to improved knowledge of how to verify and validate groundwater models, and also to the judgement of the uncertainties involved in model predictions.

The Nordic programme has made it possible for Danish and Norwegian participation in the international Biomovs-project. Here, for the first time, it has been possible to test biosphere-models in international cooperation. The study has included scenarios valuable from a waste perspective by comparing results obtained by different models. Models have also been validated by means of observed data, in particular data obtained from the Chernobyl accident.

The Hydrocoin and Biomovs projects have contributed to an increased understanding of the fundamental questions involved when mathematical models are to be validated.

The programme has also included geologic issues related to the use of crystalline rock as a final environment for a repository for high level waste. The composition of deep groundwaters with a very high salt content are of special interest.

The achievements of this four-year programme constitute a joint Nordic contribution towards a firm basis for nuclear waste management and the assessment of its safety.

SAMMANFATTNING

Kärnavfallsområdet omfattar en mångfald av frågeställningar med anknytning till många olika vetenskapliga discipliner. Det inbegriper tidsperspektiv som inte tidigare diskuterats i andra miljösammanhang. FoU inom detta område är väl lämpat för internationellt samarbete och har varit föremål för nordiskt samarbete under ett flertal år. Samarbetet har löpt inom ramen för ett vidare samarbete på kärnsäkerhetsområdet som sammanhållits av det nordiska kontaktorganet för atomenergifrågor, NKA.

De ämnesområden som behandlats under programperioden 1985-1989 är inte unika för de nordiska länderna, men de återspeglar den höga ambitionsnivån på kärnavfallsområdet i dessa länder. Programmet (förkortat KAV) har slutrapporterats under våren 1990.

Forskningsinsatserna är av förklarliga skäl koncentrerade till de två länder i Norden som har kärnkraftsreaktorer. Men flera av frågeställningarna i KAV-programmet är relevanta även för forskningsreaktorer och därmed av intresse också för Danmark och Norge. Till sådana frågor hör exempelvis att reaktorer har en ändlig livslängd och förr eller senare kommer att avvecklas, och att transporter av radioaktivt material äger rum i samtliga länder. Det har t ex varit möjligt att göra en studie rörande nedläggning av en norsk forskningsreaktor, och att bedöma transportbehovet i de nordiska länderna i förhållande till gällande regelverk. Ett förslag till nordiskt kvalitetssäkringssystem för transportbehållare har tagits fram.

Några frågeställningar i KAV-programmet har i första hand varit av intresse för myndigheter och industri i länder med kraftproducerande reaktorer. Ett sådant projekt rör frågan hur man kan hantera den situation som uppkommer efter en relativt stor skada på reaktorhärden och hur det uppkomna avfallet kan tas om hand.

Det internationella Hydrocoinprojektet, som syftat till att öka förståelsen av modelleringen av grundvattenströmning i berg har också i första hand intresserat dem som producerar stora mängder högaktivt avfall. Projektet har haft deltagande från många länder utanför Norden och har gett kunskaper om hur man kan verifiera och validera sådana modeller.

Genom det nordiska samarbetet har den nordiska deltagandet i Biomovs-projektet kunnat breddas till att omfatta också Danmark och Norge. I Biomovs har biosfärmodeller för första gången kunnat testas i internationell samverkan. Detta har gällt både scenarier som är värdefulla från avfallssynpunkt (modelljämförelser) och tester med experimentella data (validering). Olyckan i Tjernobyl har bidragit med värdefulla data.

Både Hydrocoin och Biomovs har således bidragit till att belysa bl a valideringsproblematiken, och pekat på möjligheter och begränsningar.

De nordiska insatserna har slutligen också omfattat geologiska frågeställningar och det kristallina berget som en slutlig förvarsplats för det högaktiva avfallet. Särskilt intresse har riktats mot sammansättningen på djupa grundvatten och detta har givit nya resultat. Insatserna har i övrigt kompletterat de stora program som pågår nationellt i Finland och Sverige.

Det nordiska KAV-programmet har bidragit till att skapa en fast grund för kärnavfallshanteringen och tillhörande säkerhetsbedömningar.

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1. INTRODUCTION

The public concern for the use of nuclear energy is mainly focused on the consequences of a reactor accident and on the potential harmful effects of the produced radioactive waste today and in the future. Much effort, nationally and in international cooperation, is put into research in both these fields. Nordic cooperation in nuclear safety has been ongoing since 1977 in terms of four-year research programmes.

The main emphasis in research on radioactive waste is now directed into two fields. Firstly, to enlarge the knowledge base concerning the waste itself and the methods for its management. Secondly, to provide satisfactory "proof" through safety analyses that this management will be safe now and in the future.

Of the five Nordic countries, only Finland and Sweden have nuclear power. In these countries considerable research efforts are focused on questions related to safe disposal of nuclear waste, in particular spent nuclear fuel and high level waste. This work involves the utilities as well as the authorities. Repositories for low and medium level radioactive waste are in operation (Sweden) or under construction (Finland). The major efforts are therefore concentrated to high level waste, and the power companies have large research programmes in force. The authorities also direct their work towards questions concerning acceptance criteria for repositories.

This Nordic research programme was from the start largely based on research programmes in Finland and Sweden. This means that issues of national interest have formed the basis for the Nordic work. At the same time, however, both Denmark and Norway produce nuclear waste in their research reactors, and in other activities, that has to be taken care of. The amounts of waste are, evidently, much smaller than in the countries with nuclear power. Through the Nordic cooperation it is possible to incorporate the special competence existing in Denmark and Norway.

The recently terminated Nordic programme (1985-1989) covers six different items related to the following areas of current interest:

-modelling of groundwater flow in the context of nuclear waste disposal (Hydrocoin)
-testing and evaluation of biospheric transfer models (Biomovs)
-geologic issues of interest in relation to nuclear waste disposal
-decommissioning of nuclear installations
-transport of nuclear waste
-waste handling after fuel damage in a power reactor.

A large number of scientific reports have been published giving results obtained in connection with the programme. Most of these can be found in the reference list in the summary reports of the main projects [4-8]. The Hydrocoin and Biomovs studies are published separately [1-3]. In the following, the main features of this programme are outlined.

A Nordic follow-up programme was initiated in the beginning of 1990. This new programme deals with low-level waste - how to handle large amounts in case of accidental spills, and whether it can be declassified as non-active. It also deals with the influence of climate on repositories, and how to make sure that information about the waste will be available over long time spans.

2. MODELS AS A TOOL IN SAFETY ASSESSMENT

An underground repository is the preferred option today for the disposal of highly radioactive nuclear waste and spent fuel. In the Nordic countries this means a repository several hundred meters down in crystalline rock. A number of barriers, natural and man-made, should prevent against unacceptable harm to living organisms now and far into the future. In the safety analysis it is assumed that radionuclides will eventually be transported by groundwater away from the repository. A major problem is then how to show that the leakage of radionuclides will be slow enough to fulfil a number of requirements - requirements that today are only partly or vaguely formulated. This problem is manifold and involves both a scientific process, i.e. to reach a consensus within the professional community, and a process of communication with the general public and the decision-makers. The handling of uncertainties is a crucial part in these processes which must be based on both quantitative and qualitative analyses.

The safety assessment of a nuclear waste repository is based on a series of models describing the immediate surroundings of the repository (the "near field"), the hydrology, the geosphere, the biosphere and the effects on man and the environment. Each individual model represents the processes involved in a simplified way; reality is transferred into mathematical formulas. This conceptualisation of nature and subsequent solution of the mathematical equations introduces uncertainties.

The choice of studied events (often called scenarios), the lack of experimental data and the time horizon involved also introduce uncertainties which influence the final result and its interpretation.

The Nordic programme has taken part in two international studies in which uncertainties and reliability of models utilized in safety assessment of nuclear waste repositories have been studied.

2.1 Groundwater flow modelling

Radionuclides from a leaking repository can be transported to the biosphere with the groundwater. This calls for an understanding of the groundwater flow. The overall objective of the "Hydrocoin" (Hydrologic Code Intercomparison) project is to gain a better understanding of how various ways of describing (modelling) groundwater flow will affect the safety assessment of a nuclear waste repository. The study has included tests of how accurately the participating models can solve specified problems (often called verification [1]), and how well the models can describe real world processes (called validation [2]).

As a result of the Hydrocoin verification study it can be concluded that adequate mathematical methods exist for cases with no or small variations in material (rock) properties and flowfields. With strong variations in these properties over the domain considered, the modelling is more difficult and such situations require development of better mathematical methods. It should also be noted, that the models used assume that the crystalline rock will behave as a porous medium, i.e. individual fractures in the rock are not explicitly accounted for.

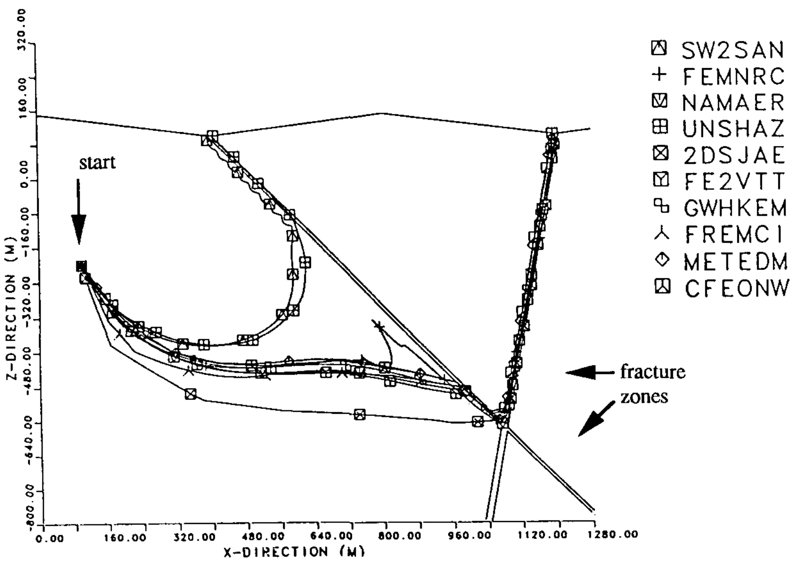

Fig 1. Tracks calculated for a simulated steady-state flow in a porous medium. There are two permeable fracture zones intersecting each other [1].

The results of intercomparison between the different codes showed that they are equally reliable as far as their mathematics are concerned. On the other hand, the accuracy of their results needs to be carefully tested for instance by independent verification.

It is important to know how accurate a model is, but it is equally important to know how well the model represents reality, i.e. how "valid" the model is. In Hydrocoin, the level of agreement between model predictions and experimental results has been investigated for five test cases based on the most suitable experimental results available to the Hydrocoin-group [2]. There were no experiments that were entirely adequate for the purpose. However, the studied cases involved several of the processes which are of importance for radioactive waste disposal. They covered different media of interest, such as crystalline rock with low water permeability and salt formations, and a variety of spatial and temporal scales.

The performed validation tests resulted in detailed conclusions regarding the applicability of the models to the studied cases and the usefulness of the corresponding data sets [2]. The understanding of the complex task of model validation has increased substantially and this insight will be of importance for further validation efforts in groundwater flow modelling. The results further showed the significance of defining appropriate measures for the comparison and judgement of model predictions with experimental data as well as the need of a close co-operation between the modeller and the experimentalist in setting up appropriate experiments.

One general conclusion is that the Hydrocoin validation effort has contributed to an increased confidence in the applicability of groundwater flow models to situations relevant to radioactive waste disposal. At the same time it is stated that most of the models used were based on the porous medium assumption, and in future validation efforts alternative models should be tested.

2.2 Transport of radionuclides in the biosphere

The groundwater is the link between the repository and the biosphere. When the radionuclides from a repository reach the biosphere, their further transport may be calculated for various pathways. In the international Biomovs (Biosphere Model Validation Study) project, biospheric transfer models have been tested and evaluated [3]. Two basic approaches have been adopted for this model testing. One approach, the "A scenarios", has involved a direct comparison of model predictions against actual observations in nature. The other approach, the "B scenarios", involved the intercomparison of model predictions and their uncertainty estimates. The eight B scenarios have been focused towards important assessment questions for which independent test data do no exist.

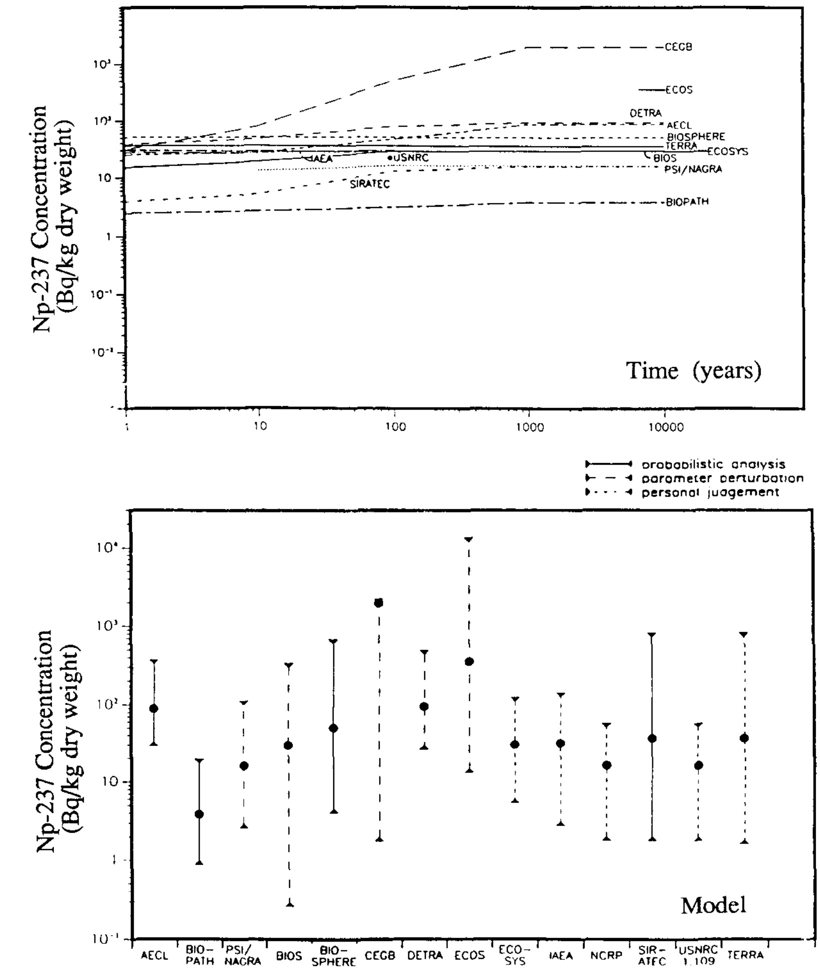

Fig 2 Calculated time-dependent concentrations of Np-237 in pasture after irrigation with contaminated groundwater and the corresponding uncertainty estimates for a number of different models [9].

The B scenarios have dealt with questions concerning accumulation of radionuclides in groundwater, surface and sub-surface soils, lake sediments, lake water and biota as functions of time. A provisional consensus has been achieved on the basis for modelling transport in and between these compartments of the biosphere. The B scenarios have especially showed the need to furher work on the radionuclide transport in the interface between the geosphere and the biosphere. The modelling effort has also revealed that radiation doses arising from build-up of radionuclides in soils and lake sediments could exceed the doses arising from comparable releases into lakes used for drinking water.

The nuclear accident in Chernobyl contributed with world-wide data to evaluate model predictions through the process of a blind test. Such a blind test is necessary to evaluate accuracy. The results from the A scenarios have demonstrated that relatively large uncertainties are present also for the transfer of I-131 and Cs-137 through terrestrial and aquatic food chains. These processes were previously thought to be well understood. Even though the A scenarios are superiour to the B scenarios when it comes to increasing the confidence in the model predictions, the A scenarios are not directly applicable to the effects of radionuclides migrating from a waste repository.

The Biomovs has revealed a high lack of confidence for predictions made far into the future and for less well studied radionuclides. In these cases the uncertainties in the model predictions were generally much larger than one order of magnitude. However, the presence of large uncertainties for the predictions may not necessarily lead to a lack of confidence in the overall assessment of dose or risk. It was also concluded that an increased complexity in model structure does not guarantee increased accuracy.

3. EXPERIMENTS IN GEOLOGY

Repositories for high level waste are planned to be situated deep in the crystalline rock in Finland and Sweden. Extensive work is going on in the two countries, financed by the power companies, to investigate the bedrock and its suitability for future repositories for high level waste and spent nuclear fuel. These rock studies include geochemistry, hydrology and tectonics. The Nordic programme has given support to parts of this research programme covering deep groundwaters, dating of fissure minerals and late tectonic movements in the bedrock [4].

One main objective has been to investigate the occurrence of saline deep groundwaters and their origin. Water samples were taken in a large number of old, deep (normally more than 500 m), drill holes in different geological environments, mainly in Finland. A portable water sampler was developed to allow sampling in these slim drillholes. The water salinity is found to vary substantially and its chemical composition is often different at different depths. High salinity chlorine-waters, up to 17%, were found. Saline waters were normally found at depths below a couple of hundred meters. In coastal areas the saline water is nearer the ground surface. The origin and the age of these waters may differ, but generally they are very old. Depending on the geographic location the origin can be old sea water (near the coast), but often it is believed to come from water-rock interactions, in which case the water must have had a very long residence time in the rock. The most saline deep groundwaters are in general also rich in gases, mainly methane and nitrogen.

The results seem to differ from what is generally obtained in both Finnish and Swedish investigations concerning nuclear waste disposal, in which the occurrence of high salinity waters is assumed to be more rare. The differences may be due to topograpy and other factors which have a large influence on the flow of groundwater.

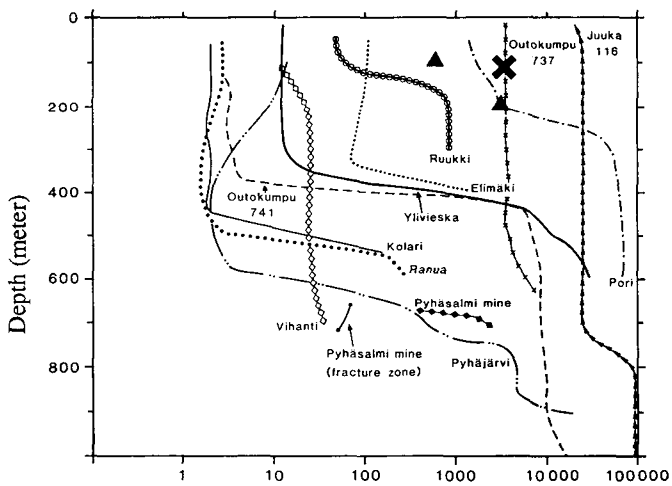

Fig 3 Chloride content in water versus depth below ground level in some drill holes [4].

High salinity waters can exist only when the groundwater flow is very small. It has been suggested that this may be one reason for considering the suitability of such a bedrock for a repository for spent fuel. On the other hand it is uncertain to what extent building of a repository in such an environment would change the flow pattern.

In another part of the geology programme methods for estimating the age of minerals in geologically young fissures have been developed. With these methods it would be possible to indirectly date the neotectonic movements. The fission track technique utilizes the spontaneous fission of U-238. In principle, the number of tracks in the mineral is a measure of its age. The study shows, however, that fission track dating of fissure minerals is impossible due to a very low content of uranium and to the mobility of the uranium.

On the other hand it has been found that C-14 analysis could be a possible way for dating the calcites that are located in the fissures. This method is promising for further development.

Finally, the project on neotectonic movements has been concentrated on studies of recent movements in northern Finland and Sweden (i.e. in the 10 000 years since the last ice-age terminated). The results indicate a large tectonic activity in late glacial and early postglacial time (8 000-10 000 years ago). These movements seem to have mainly followed older faults and fracture zones, even though it has been claimed that some movements might also be of younger origin. The uncertainties here will be further investigated. It must be recalled that 10 000 years is very short time in the geological perspective.

4. DECOMMISSIONING OF NUCLEAR INSTALLATIONS

Nuclear reactors have a limited life time governed by safety factors and economy. Once a reactor is taken out of operation the decommissioning process starts. This process can vary in many ways. Experience from full size decommissioning of a nuclear power reactor is not yet available. The main experience so far comes from decommissioning of smaller reactors of various constructions, especially research reactors.This is the case also in the Nordic countries where a few research reactors have been totally dismantled, i.e. all radioactive material removed and the area released for use free from restriction. In addition three reactors have been decommissioned to the stage where all easily dismantled equipment is removed, and radioactive components are concentrated to minimal space. Other areas are cleaned and released for other use, but there will be continued periodic inspections. Finally, one reactor in Sweden is in a stage where all fuel has been removed from the reactor, all systems are drained and the control system is disconnected. There is restricted access to the plant which is periodically inspected.

It does not seem probable that actual dismantling of nuclear power reactors will be undertaken in the Nordic countries during the nearest decade. The purpose of the project on decommissioning has been to improve the standard of knowledge, and in particular to cast light on some issues that need to be analysed before a large decommissioning programme starts [5].

To a certain extent, the work has been based on needs within the regulatory authorities to obtain information that will form the basis for forthcoming regulations. These may *i.a.* deal with limits for what will be considered as non-radioactive. These limits, which will allow for recycling of valuable metals with or without restrictions, are of great economic importance. But a classification of radioactive material will also decide the type of repository needed for the decommissioning waste. In principle it is easy to estimate the activity in various parts of the reactor when the operation characteristics of the reactor is known. There exist uncertainties, however, and these have to be diminished in order to build repositories of appropriate dimensions.

Studies of the activity induced by neutron irradiation and the surface contamination in different parts of a reactor system have been a part of this programme. Experimental investigations were carried out and used as a basis for theoretical evaluations including testing and development of models.

All radioactive waste generated during decommissioning will have to be transported to a repository. The present regulations for transports of radioactive material were scrutinized with respect to decommissioning waste. The general conclusion is that in all Nordic countries there are adequate transport systems with which the decommissioning waste can be transported in accordance with national and international transport regulations. However, there exist some practical details which should be further considered to obtain an optimal solution.

It is difficult today to estimate the exact time for decommissioning of the large nuclear power reactors. The decommissioning strategy can also vary. It is therefore important to make sure that the the proper documentation of the plant and its operation history will be available when the time comes. Such information exists today and is handled by the staff of each reactor. However, the information may have to be rearranged.

Even though reasonably good estimates of waste amounts and their classification into different activity classes exist today, there are always uncertainties due to differences in operation in the future, and to the life-time of the different reactors. These uncertainties, however, can be reduced as time goes by in contrast to many of the uncertainties which have been discussed in previous sections. Some uncertainties remain, related to difficulties in measuring the activity in some parts of the reactor system.

5. TRANSPORT OF RADIOACTIVE WASTE

Transport of radioactive material takes place in all Nordic countries. The origin can be waste from nuclear installations but also from other types of industry, from research establishments and from the medical sector. Waste quantities from reactor operation are increasing, and in the future also decommissioning waste will need to be transported. Certain events, e.g. a large fuel damage in a reactor or a reactor accident, would of course give rise to increasing amounts of waste with higher levels of activity. Such events will also put very special demands on the transport system which would have to be adjusted to the prevailing circumstances. (The treatment of waste resulting from a larger fuel damage is described in section 6.)

A survey has been made of the amount of radioactive waste material to be transported in the Nordic countries, the type of containers that are used and the transport systems available [5]. There are differences especially between Finland and Sweden on the one hand and Denmark and Norway on the other due to the fact that only the first two countries have nuclear power reactors.

National safety regulations in the Nordic countries are in accordance with internationally accepted recommendations from the IAEA. The latest of the IAEA regulations from 1985 are presently being implemented in the Nordic countries.

The transport of radioactive material is performed according to stringent requirements, and especially for nuclear transport it is characterized by an integrated system approach where each link involved provides a safety barrier with its own specific efficiency. In view of forthcoming revisions of the IAEA transport regulations, it is suggested [5] that the total risk picture of the entire transport system should be taken into account when evaluating the safety of nuclear transports.

Transport of radioactive material across national borders is in principle also governed by the IAEA transport regulations. National differences concerning control and verification of packagings for radioactive waste may, however, lead to complications in such transfers. Internationally accepted, uniform requirements, concerning the desired quality level of the manufactured packagings and their recurrent inspection are desirable. With this in mind a guide for a control programme has been produced. Control programmes for manufacture and recurrent inspection are outlined for various types of packages [7]. A description of how to plan and set up actual control plans for a specific container has also been produced. It is hoped that these control procedures and acceptance levels will find acceptance within and perhaps outside the Nordic countries.

6. WASTE FROM AN ACCIDENT

The capacity of nuclear waste repositories is planned and built for the "normal" waste production of low, intermediate and high-level waste, and this is also true for the transport systems. But events with low probability may occur and result in large amounts of radioactive waste. The most striking case is of course an accident like the one in Chernobyl, where the large contamination of the environment causes extensive waste problems in addition to all other problems. But also the reactor accident at Three Mile Island gave rise to waste handling problems at the site.

The waste plants on the reactor sites in the Nordic countries are designed to annually receive a certain amount of various categories of radioactive waste. The capability of handling the waste that might arise in case of a serious accident that involves fuel damage has now been investigated [8]. A reactor accident was postulated to take place in a BWR plant and with a fuel damage leading to a release of 10% of the core inventory of noble gases. The results obtained are based on a detailed accident scenario. To make the study more realistic, one particular Swedish reactor was chosen as a reference (Oskarshamn 2).

The study shows that this postulated accident, where no fatal damage is caused to the core structure or fuel, would anyhow stop the operation of the reactor for several years, or possibly close down the reactor for ever. The major factor which would prolong the shut down, is the damage to the electrical equipment caused by cooling water filling the reactor containment. Mechanical and electrical equipment would probably also be damaged during the decontamination of the surface of the reactor vessel and the containment.

Type of waste	Mass (kg)	Volume (m^3)	Total surface area (m^2)	Surface activity (GBq/m^2)	Total (GBq)
Ventilation system (fans)	700	1	25	7.2	180
Cables	11000	1.9	900	7.2	6500
Motors	3800	2.4	50	7.2	360
Components, Solenoid valves etc	2000	1	6	7.2	43
Mineral wool insulation	4500	30	-	-	5500
Caposeal (reactor vessel insul.)	17000	70	-	-	20000
Concrete surfaces	9200	4	2000	7.2	14000

Fig 4. Waste generated in the reference reactor [8] two years after the postulated accident .

The major cleanup step is supposed to start not sooner than three months after the accident. A difficult part of the cleanup would be the surface decontamination of the reactor vessel and the containment and equipment therein. The existing cleanup and solidification systems at the site should be used as much as possible. Different preparatory measures must, however, be taken before utilizing these systems. The solidification capacity of the solid waste system of the reference plant would be insufficient and would be the time limiting step in the early stages of the cleanup process, while the uptake of nuclides on ion exchangers would be the limiting step at the very end of the process when the water remaining in the containment is purified.

Solidified waste is assumed to be transferred to concrete moulds. It was shown that a high surface dose rate (300 mSv/h) could be handled in the reference reactor. However, there will be a need for equipment that allows remote control operations, and probably also for additional radiation shielding.

A main conclusion of the study is, that in the reference reactor it is possible to handle a serious core damage corresponding to a release of 10% of the noble gas inventory. Some minor modifications would be required in the waste plant after the event. This conclusion is, however, to a large extent reactor specific.

This study is limited to the reference reactor and differences and similarities with other reactors in Finland and Sweden has not been further investigated.

7. CONCLUDING REMARKS

One of the main tasks of research in nuclear waste management is to clarify to what extent various safety features can be adequately predicted, to estimate uncertainties involved and, when possible, to compensate for these uncertainties in one way or another.

The Nordic programme is only a minor part of the efforts taking place in this respect. Although the programme was not at the outset planned to deal specifically with the overall question of uncertainties in calculations and predictions, certain general observations can be made in the light of the results obtained in the individual projects of this programme.

Some sequences in waste management can be predicted rather accurately and without larger uncertainties, and in some cases the uncertainties will decrease with time and increased knowledge. That is the case with uncertainties related to transportation of waste, and to the estimation of waste quantities from the decommissioning of reactors, two questions dealt with within the Nordic programme.

In other sequences, uncertainties are significant and often increase when larger time spans are considered. For the purpose of safety evaluation, the consecutive steps in a chain leading from the source (radionuclides in a repository) to the effects on man and environment are described by means of models. Such models can be improved to a certain extent, firstly by introducing corrections to their formulation and to the parameter values that are built into the models. Secondly, the models can to some extent be validated by means of observations in nature of today, be it in the geosphere where the water flow in the rock has been dealt with, or in the biosphere where models for the transfer of radionuclides through soil, water and plants have been investigated. Improved knowledge is available to use these models for projections into the future although there is no direct way in which predictions in the future can be quantitatively verified. However, by estimating uncertainties in the predictions under various assumptions, it can be indicated whether radiation doses to man due to various radionuclides escaping from a repository may at all reach a level of concern.

Another aspect of uncertainty that contributes to the overall picture is the geology of the formation where the repository is located. Investigations of the past history over thousands and millions of years may help to estimate in what time frames tectonic movements, fractures along existing faults and other phenomena may introduce uncertainties in the projections. It is important to keep in mind how the decay of radionuclides reduces their offensiveness over time periods where geologic changes may occur.

The last example of uncertainties dealt with in the programme concerns events that may lead to abnormal, i.e. not normally predictable, releases of radionuclides. In this case the scenario was a major accident in an operating reactor leading to a sudden generation of waste. For this particular scenario it is shown that countermeasures can be taken to handle the situation. In general, it is a delicate task to assure the completeness of the studied scenarios in order to illustrate the safety of a certain waste management scheme.

The Nordic programme has dealt with some specific questions of importance. Some of these questions are of the kind that rather accurate answers can be obtained and present uncertainties be decreased by research. Some questions, on the other hand, are such that further research can only marginally decrease the uncertainties. For a number of questions uncertainties are inherent and therefore can not be reduced by further research. However, they have to be accounted for in policy decisions, regulations or in design and operation of facilities for waste conditioning and disposal.

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