SOU

1998:68

NUCLEAR WASTE

state-of-the-art reports 1998

KASAM

STATENS RÅD FÖR KÄRNAVFALLSFRÅGOR

Swedish National Council for Nuclear Waste

This report can be ordered from:

Fritzes kundtjänst
106 47 Stockholm
Orderfax: 08-690 91 91
Ordertel: 08-690 91 90
E-post: fritzes.order@liber.se
Internet: www.fritzes.se

Swedish title: Kunskapsläget på kärnavfallsområdet 1998

KASAM has issued such state-of-the-art reports also in

1986 (ISBN 91-38-09767-2)
1987 (ISBN 91-38-09938-1)
1989 (ISBN 91-38-12264-2)
1992 (ISBN 91-38-12749-0)
1995 (ISBN 91-38-13952-9)

All these reports are in Swedish. The 1998 report is the first in this series to be translated into English.

The translation has been done by EnergiTek Translations.

Cover picture: ”Landscape”, textile art by Maria Triller
Photo by Tord Lund.

NORSTEDTS TRYCKERI AB
Stockholm 1999

ISBN 91-38-21107-6
ISSN 0375-250X

Contents

Preface

This report is the sixth in a series of state-of-the-art reports - published since 1986 - on nuclear waste, officially submitted by KASAM to the Swedish Government in May 1998.

It is not possible for each of these reports to provide a comprehensive view of the state of the art within nuclear waste. Instead, with each report, KASAM attempts to examine a number of topical issues in the debate which should be presented so that they can be easily understood. Besides the Swedish Government, the reports are aimed at politicians and communities which are involved in the siting of a repository for spent nuclear fuel, environmental organisations and other interested parties.

"Nuclear Waste, state-of-the-art reports 1998" was compiled by:

Chapter 1	Anne-Marie Thunberg, KASAM
Chapter 2	Kjell Andersson, Karinta-Konsult (KASAM) and Olof Söderberg, Special Advisor to the Government for Nuclear Waste Disposal
Chapter 3	Bengt Erlandsson, Lund University, Robert Hedvall, Studsvik Radwaste and Sören Mattsson, KASAM
Chapter 4	Lennart Devell, MSE-Konsult
Chapter 5	Nils Rydell, KASAM
Chapter 6	Johan Berglund, GeoMap West and Jimmy Stigh, KASAM
Chapter 7	Eva-Lena Tullborg, Terralogica AB and Jimmy Stigh, KASAM
Chapter 8	Shankar Menon, Menon Consulting AB
Chapter 9	Kjell Andersson, Karinta-Konsult (KASAM)
Chapter 10	Kjell Andersson, Karinta-Konsult (KASAM)
Chapter 11	Olof Söderberg, Special Advisor to the Government for Nuclear Waste Disposal

KASAM, the Swedish National Council for Nuclear Waste, has the following members (spring 1998):
Camilla Odhnoff, Chairman, Ph.D., Plant Physiology, Former Governor
Rolf Sandström, Vice-Chairman, Professor, Materials Technology, Royal Institute of Technology, Stockholm
Göran Andersson, Professor, Electrical Energy Systems, Royal Institute of Technology, Stockholm
Britt-Marie Drottz Sjöberg, Professor, Social Psychology, Norwegian University of Technology and Science, Trondheim, Norway
Willis Forsling, Professor, Inorganic Chemistry, Luleå Technical University
Sören Mattsson, Professor, Radiophysics, Lund University
Gert Knutsson, Professor em., Hydrogeology, Royal Institute of Technology, Stockholm
Anneli Salo, Ph.D., Environmental Radiation Protection, Former Head of Department, Helsinki, Finland
Jimmy Stigh, Professor, Geology, University of Gothenburg
Anne-Marie Thunberg, D.D., Ethics, Editor, Sigtuna
Lotta Westerhäll, Professor, Public & Social Law, University of Gothenburg

Experts to KASAM:
Olof Söderberg, Ph.D., Special Advisor to the Government for Nuclear Waste Disposal
Nils Rydell, M.Sc.Eng. (Senior Technical Advisor)

Secretary to KASAM:
Tor Leif Andersson, Ph.D.

Consultants to KASAM:
Kjell Andersson, Ph.D.
Harald Åhagen, Engineer

Summary

The issue of nuclear waste disposal has come to symbolize the question of how the current generation is generally assuming responsibility for the long-term consequences of human impact on the environment. How far into the future can we, in all credibility, assume responsibility? Does our moral responsibility have a time limit? How can we act in a credible manner today, on the basis of our current understanding of the long-term consequences of our actions?

These are the key issues dealt with in Chapter 1 of this report, The temporal scope of ethical responsibility. These issues are examined in the light of early studies by KASAM and the position adopted by KASAM as early as 1987 as well as in the light of the considerable international debate which emerged somewhat later. Two main approaches to the search for overriding principles are briefly outlined. The one emphasizes an equitable intergenerational distribution of risks and burdens while the other follows the equal opportunities principle, emphasizing an equal distribution of resources with scope for freedom of action for future generations.

However, considerable difficulties arise with both approaches when it comes to making the transition to tangible strategies for present-day action. In the long-term perspective, the problems relating to uncertainties are considerable and this raises the question of the democratic credibility of the decisions that we make today. The credibility of the basis for decision-making decreases the further the time-scale extends into the future. The time gap is too large between the time of decision-making and implementation

of measures and the distant future to which these decisions and measures apply. However, by using concepts such as "a chain of generations" and "rolling present" or the transfer of responsibility between generations, this time gap, which is of decisive importance for credibility, can be bridged.

An important conclusion of this section is that we are responsible for looking for the optimum solution on the basis of the knowledge that we have today. Since our knowledge of the long-term development of the repository is incomplete, the assessment of the consequences of our solution will be uncertain. For this reason, we must choose a solution that is sufficiently open to give future generations scope for action. However, unavoidably, there are cut-off points in time, both with respect to the value of preserving freedom of action and to our responsibility for the consequences of our action. Our possibility for assuming a moral responsibility decreases on a sliding scale with time.

Chapter 2 deals with the decision-making process. KASAM arranged - together with the National Co-ordinator for Nuclear Waste Disposal - a seminar in Umeå on April 8-10, 1997, with the aim of discussing the decision-making process within a broader circle of expertise. This chapter provides a summary of impressions from the seminar and from subsequent discussions. KASAM has observed that, recently, much in the decision-making processes has been clarified through government decisions. However, further clarification is necessary, especially with respect to the selection of sites for site investigations. This stage of the site selection process is of greatest importance for the municipalities concerned. Various government decisions require extensive reporting by SKB. SKB's reporting must include site selection criteria and a system analysis with an account of the method issue. However, it is unclear how these reports will be reviewed, what role the competent authorities will play in the review process and the principles on which site selection will be based.

The subsequent three chapters deal with the theme of Risk Comparisons and Safety Assessment.

Chapter 3 provides a description of how radioactive waste arises within various parts of the energy sector, not only within the nuclear energy sector. The nuclear industry's radioactive releases, radiation doses and waste problems are well known and discussed. The radiological problems which arise in connection with oil recovery attract less attention in Sweden, mainly due to the fact that we do not produce oil. The radiation doses to the personnel from deposits in pipelines and cisterns of naturally occurring radioactive substances which originate from the bedrock and seawater, can be substantial and regular cleaning may be required. This results in low- and intermediate-level waste which must sometimes be handled for land-based disposal. The radiological impact of hydro power is mainly associated with the radon problems in underground storage facilities which, in the same way as for other indoor and underground work, must be dealt with using improved ventilation. Under normal conditions, biofuel combustion results in minor releases of naturally occurring radioactive substances. The quantity is greater for peat than for wood (wood chips). Since the biosphere has been contaminated with radioactive fallout from atmospheric nuclear bomb testing by the world's superpowers, the releases have increased. Radioactive fallout from the Chernobyl accident has resulted in such high 137Cs concentrations in biofuel from certain areas in Sweden that the ash must be deposited in specially designed landfills. Similar types of landfills are already being used for ash from coal, primarily on the basis that this type of ash contains toxic heavy metals etc.

Chapter 4 is devoted to the transportation of spent nuclear fuel. The transportation of fairly newly irradiated spent nuclear fuel from the nuclear power plants at Barsebäck, Forsmark and Ringhals to the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB), located on the Simpevarp peninsula, next to the nuclear power plant) has been conducted for many years using the purpose-built ship, Sigyn. These shipments have not attracted any significant interest from the general public and have also been carried out without any incidents or accidents. KASAM has

detected a certain fear and uncertainty, especially among politicians and others in the community which may be affected by such shipments. This has been observed now that discussions are focusing on the possible transportation on land - from a future encapsulation plant to a future repository, which may be located on the coast or inland - of spent nuclear fuel, which has been encapsulated for final disposal. In this chapter, KASAM intends to give a balanced view of what might happen in connection with this type of shipment and of the risks which this could entail for people living in or visiting the areas along the transportation route. The conclusion is that the risk of the general public being affected by these shipments from the standpoint of ionizing radiation is insignificant. However, these shipments will be very heavy with vehicle weights of around 100 tonnes and a network of roads capable of sustaining such loads will be necessary. One risk which is only marginally dealt with in this chapter is the risk of invasion by demonstrators. Recent events in Germany, in particular, indicate that the transportation of spent nuclear fuel by land is very vulnerable to attack by various organizations wishing to wage war against nuclear power and it has been found that a massive police presence has been necessary in order to be able to conduct the transportation as intended. So far, in Sweden, we have not had any such actions, probably partly due to the fact that we use a maritime system for the transportation of spent nuclear fuel.

In Chapter 5, a summary is presented of a couple of KASAM seminars held in 1997. The aim of the seminars was to bridge the gap between, on the one hand, the requirement regarding comprehensiveness and scientific stringency with respect to the reporting of safety assessments prior to licensing by the competent regulatory authorities and, on the other hand, the requirement on comprehensibility with respect to those who lack specialized knowledge but would like to form their own opinion of the safety of the repository. This chapter deals with the application of safety assessment at different stages of the work on designing a safe repository, the method used to analyze the future development of the repository and the content of the safety assessment. It has been found that the latest design of the canister means that the

previous analyses of the engineered barriers are no longer relevant. The direction of further safety assessment work is being discussed in the light of the requirements that SKI establishes with respect to the safety assessment prior to future licensing actions.

The two subsequent chapters relate to Knowledge of the Bedrock.

The first of these two chapters - Chapter 6 - describes the area of fractured bedrock. Knowledge in this area has improved considerably in recent years and, in addition, the attitude to the importance of fractures has changed over the years. During the initial years of the nuclear waste programme, considerable interest was centered on "fracture-free rock". However, afterwards, it was found that a moderately fractured bedrock and a deep repository surrounded by fracture zones which can absorb bedrock movements might be more desirable. On a large scale, the bedrock surrounding a repository should absorb and distribute any future changes in stress without creating completely new fracture systems. It has been found that a large number of the fractures and deformation zones found in the bedrock today are re-activated, i.e. movements have occurred in them at different times. Today's large-scale systems of fracture and deformation zones were formed several hundred million years ago.

Chapter 7 focuses on bacteria. In recent years, there has been improved knowledge of bacteria present in very deep groundwater and of how these can affect the chemical environment surrounding a copper canister in a KBS-3 repository and thereby present a threat to such a repository. Sulphate-reducing bacteria can convert sulphate into sulphide. High sulphate concentrations in the immediate vicinity of the canister increases the risk of corrosion and should, therefore, be avoided. However, the research results available indicate that the bacterial activity inside the bentonite will be very low due to the low availability of water.

Chapter 8 deals with the decommissioning of nuclear power plants. As nuclear power plants reach "retirement age", they will be

decommissioned and then dismantled. Of the some 440 nuclear power plants which, according to the IAEA, were in operation in 1995, about 370 will reach the age of 40 during the period of 2010 - 2030. Around the world, intensive development work is in progress with respect to technology for dismantling nuclear power plants and to restore sites where nuclear power plants were formerly located to "green field conditions" (i.e. to the original condition, before the plants were constructed). The clearance of scrap metal from the nuclear industry for subsequent re-use is also an interesting - although controversial - subject which is dealt with in this chapter.

The report concludes with three chapters within the area of Nuclear Waste and Nuclear Waste Research in Other Countries.

An overview of the activities in four countries (Finland, Great Britain, France and Canada) within the area of nuclear waste is provided in Chapter 9. Different procedures are applied in each of these four countries for environmental impact assessment and public involvement in method and site selection. Recent events are a source of valuable experience for us in Sweden. Thus, the nuclear waste programmes in Canada and Great Britain have met with setbacks in Canada and Great Britain, with respect to method assessment and site selection, while the site selection programmes in Finland and France show significant progress. KASAM's conclusion is that the responsibility taken by the Government and the actual possibility for the local community to have insight and influence are two important factors for the credibility and results of the nuclear waste programme.

A separate account of research within the area of nuclear waste, which is being conducted under the auspices of the European Union (EU) is provided in Chapter 10. KASAM notes that the level of Swedish participation in the Fourth Framework Programme is low, even taking into account the fact that Sweden only recently joined the EU. KASAM has noted with satisfaction that Sweden, through the Royal Institute of Technology, Stockholm is responsible for the co-ordination of work within the research area of "Impact of the Accelerator-based Technologies on Nuclear Fission Safety".

Through the programme, Swedish researchers have access to funds for research which will lead to improved knowledge on transmutation. In general, the Swedish nuclear waste programme - conducted by SKB - has made considerable progress compared with most of the programmes in the EU member states. The joint international work being conducted at the Äspö Hard Rock Laboratory outside the EU programme should also be mentioned. However, in KASAM's view, there is good reason for industry and the authorities to stimulate increased Swedish participation in the Fifth Framework Programme, which is now being initiated. The greater opportunities for exercising influence which this would lead to and the research funds available from the EU are sufficient reason for such a focus. The conditions for creating good research projects in co-operation with other EU member states should also increase through the focus which can now be distinguished with work concentrating on risk assessment and ways of enabling the participation of the general public in the related decision-making processes.

The report concludes with a chapter - Chapter 11 - devoted to the possible disposal of foreign nuclear waste in Sweden. The question is often raised of whether Sweden could be forced to receive foreign nuclear waste for final disposal in Sweden or whether we, ourselves, could send our waste abroad for disposal. This chapter gives clear decisions on laws and regulations regarding this point, both with respect to Swedish legislation and EU legislation. The review shows that Swedish legislation contains a regulation based on the principle of the prohibition of the final disposal of foreign nuclear waste in Sweden, that similar approaches have been adopted in other EU member states with a substantial nuclear power production, that - in connection with Sweden joining the EU - it was established that the Swedish legislation is compatible with EU's system of regulations, that an international convention signed in autumn 1997 clearly recognizes the right of each member state to make independent decisions regarding the importing of foreign spent nuclear fuel and radioactive waste to its territory as well as that both the European Commission and the European Council

share the view that there is a possibility for voluntary co-operation between member states concerning the final disposal of radioactive waste.

1 The temporal scope of ethical responsibility

How can we be credibly responsible today for actions and decisions, whose consequences extend so far into the future that we completely surpass the human scale of time? Is there a temporal limit for our moral responsibility? If so, how do we set this limit without renouncing responsibility for future consequences, and do it in such a way that a responsibility for the future is included in the actions we take today? These are the overarching questions to be dealt with in this chapter.

The questions are hardly new. They have been a fact-of-life for The National Council for Nuclear Waste (KASAM) since the first report on Nuclear Waste – The State of Knowledge appeared in 1986. Internationally, too these questions have become the objects of increasing focus for the debate on the way in which today's generation takes its responsibility for nuclear waste as well as for mankind's general long-term impact on the environment. There is by now so much information available that it is natural for an analytical overview of this material to be included in a report on the state of knowledge on nuclear waste. Today, the basic ethical questions of responsibility comprise an integral part of our work to find a feasible way to manage nuclear waste.

The breakthrough for this approach came at a later date than KASAM's initial and fundamental work, which makes it natural to begin with a brief summary of the main points of that work. We will subsequently expand the perspective by presenting the broader ethical discourse that also formed the background for KASAM, after which we will briefly sketch the overriding principles as they have been articulated in a number of contexts. Two basic

approaches are distinguishable. According to the first one, emphasis is placed on *an equitable intergenerational distribution of risks and burdens*. The other follows the equal opportunities principle with emphasis on a fair distribution of resources for future generations aimed at a free scope of action.

Yet, both approaches lead to difficulties when the principles must be transformed into a course of action. One primary reason is the degree of uncertainty due to the extended time factor. This is dealt with in a special section, which concentrates on uncertainties over varying time spans. The final section attempts, using the concepts "a chain of generations" and "rolling present", to find a responsibility link between the present and the future that will enable us to create a credible process for decision-making and actions.

1.1 KASAM – an early start

Already in the report "Nuclear Waste – The State of Knowledge" of 1986, KASAM presented a premise to illustrate the topic of the final disposal of nuclear waste from an ethical viewpoint under the heading "Final Disposal – not solely a technical, scientific or financial problem". The premise dealt with the gap created by the long timespan between our present responsibility for long-term consequences and the uncertainty as to how to meet the responsibilities that we have shouldered. This was further evaluated and developed at a multidisciplinary seminar with the theme *Ethical Action in the Face of Uncertainty* in 1987, where the main question pertained to our generation's responsibility for nuclear waste in relation to future generations.

Without attempting to follow the whole line of reasoning, we can summarise the main steps as follows. We have the absolute responsibility to manage waste in such a way that we do not transfer greater risks to future generations than we are prepared to accept ourselves. However, since we are not in a position to foresee all future consequences, our responsibility is characterised

by a dilemma of uncertainty: we act, regarding the long timespan, with at least a degree of uncertainty. For this reason, the systems that we put in place must be designed with this unavoidable uncertainty in mind. We must have the capacity to repair and inspect.

This conclusion is not merely an attempt to deal with the dilemma of uncertainty. In 1986, KASAM maintained that the relationship to future generations is not solely determined by considerations of potential risks to life, health and the environment. We should also apply to future generations the same attitudes toward human beings that we consider to be fundamental to the view that we have of ourselves and of our own responsibility. In this attitude, commonly considered humanistic, one apparent tenet is the guarantee to future generations of the same right to integrity, ethical freedom and responsibility that we ourselves enjoy. Our assessment of the future consequences of our technical systems must also encompass this right or provide scope for *freedom of action*. Freedom of action as a value to be considered in our choice of strategy gets more weight due to both the uncertainty and to the insight that all technical systems are designed by fallible people.

This is a brief background to the twin conclusions drawn by the multidisciplinary seminar in 1987, known as the KASAM principle: *A repository should be constructed so that it makes controls and corrective measures unnecessary, while at the same time not making controls and corrective measures impossible*. In other words, our generation should not place the entire responsibility for the repository on future generations but, on the other hand, should not deprive future generations of the possibility to assume responsibility. The objective was also formulated in two parts: safety in operation combined with reparability, with controls not necessary, but not impossible, storage under safe circumstances but also scope to make changes.

This objective also questioned the prevailing view at the time that it is the responsibility of our generation to solve the disposal problem in such a way as to secure that the repository will not require monitoring once it has been sealed. Since KASAM

considered freedom of action to be a value, future generations must be free to use the waste as a resource. *Retrievability* was then included in the requirements for the design of the repository.

The objective was formulated with full responsibility resting on our generation. It was not a question of ignoring the long-term consequences of our actions today or to relieve today's generation of its responsibility for these consequences. As was brought to light in the moral and philosophical discussion at a later seminar with the theme *Uncertainty and Decisions* in 1990, analyses of consequences of all necessary decisions must include more than the concern for future health and environment hazards. It is equally important to also consider fundamental ethical values such as assumption of responsibility, freedom of action and personal autonomy, respect for justice and equality – values which otherwise are an integral part of certain welfare theories and of concepts of the components for 'a good life'. In other words, the consequences must be calculated with a conscious regard for the right of future generations to develop and apply these values

Interestingly enough, the moral and philosophical discussion at the seminar in 1990 showed that the value, discussed and questioned at the time, of freedom of action for people in the future, should be a vital component in cost-benefit or risk analyses. This is important *on the one hand* because of the instrumental value that this principle can have – our generation may make mistakes and the freedom of action of future generations can be a valuable means to avoid future problems. The possibility exists of repairing the repository or of managing the waste in another way. *On the other hand* it is also important due to the fact that this value is part of the broad definition of 'a good life' in general.

Accordingly, we have returned to the main tenets of the premise from 1986 and the detailed examination which took place at the multidisciplinary seminar in 1987. Later discussion, particularly in the international arena, along with the continuing developments in regard to nuclear waste disposal, has served to further intensify the issues. Before taking a closer look at this material, a conclusive aspect should be added to the broader ethical context, in which the problem of nuclear waste is included, and

which, as has already been suggested, formed the framework for KASAM's early standpoints.

1.2 Future-oriented – contemporary ethics

The heading of this section has close ties to the German-American philosopher Hans Jonas' groundbreaking work *The Imperative of Responsibility – In Search of an Ethics for the Technological Age* (1973/1979) and is on purpose somewhat exaggerated. It is not a question of "from" – "to", but that the ethics of Hans Jonas always insists that we are confronted with "Actions (even though no longer that of the individual subject) with an unprecedented causal reach into the future, accompanied by a predictive knowledge that, despite its inadequacies, far surpasses anything that preceded it". Added to this are "the magnitude of future effects", often irreversible. The temporal and spatial horizons of actions have increased radically.

How can we build the responsibilities of today into the horizons of the future? How can we handle a change of focus from the individual as ethical subject to society as a clear subject of responsibility, or to public ethics focusing on the long-term consequences of science, technological development and political decisions? Can we ever achieve the level of knowledge that in Hans Jonas' words "is commensurate with the causal scale of our action"? Are we not forced to take an ethical stand onto a gap that can never be bridged between the predictive power of knowledge and the power that our actions have far into the future?

We do not have the same ethical tradition to fall back upon in questions like these as we do in the case of the individual's behaviour in relation to his contemporaries. Rather, we find ourselves on new ethical ground. The realisation of the inevitable responsibility for the future that is an integral part of ethics also comes at a relatively late point in time. The breakthrough of the

burgeoning environmental consciousness and ecological thinking from the 1960's has played a decisive role. This change is mirrored, particularly in the USA, in the growing amount of literature where the concept of *intergenerational equity*, that is, where our responsibility for an equitable distribution between the generation now living and future generations has become a central issue.

In regard to the international discussion on the disposal of nuclear waste, it is apparent that the role played by the intergenerational equity principle in recent years is clearly connected to the World Commission on Environment and Development report *Our Common Future*, 1987 (sometimes also called the Brundtland Commission's report) with its key concept *sustainable development*, and to the later UN conference on the environment and development in Rio de Janeiro in 1992. This becomes evident in the concerted opinion of the Radioactive Waste Management Committee, OECD's nuclear energy bureau, which was published in 1995: *The Environmental and Ethical Basis of Geological Disposal*.

This connection also clearly puts the question of our responsibility for nuclear waste in a broader context of environmental policy. It is true that nuclear waste is part of a large and important general waste problem, indeed of man's impact as a whole on our life environment, resulting in all sorts of conceivable threatening ecological effects. Nuclear waste is certainly unique due to the radiation risks, but shares the long time perspective with a number of other long-lived toxic substances such as mercury. At the same time it differs from mercury in that the different various radioactive substances have different half-lives.

In a broader perspective, there is general agreement that we need a wider discussion of the ethical values regarding our emissions of foreign substances into the air and water and the effect that these may have on future generations. The problem of nuclear waste holds a unique position here due to its known volumes and directly measurable hazard. For this reason, nuclear waste has in a positive way become the area where our present responsibility is tangibly linked to the responsibility for the conceivable consequences of our actions so far into the future that

it exceeds the limits of the human imagination. *"Contemporary ethics"* and *"future -oriented ethics" converge*.

Therefore, it is hardly surprising that the particular question of the nuclear waste will be of great model importance since it forces us to take long-term ethical aspects into serious consideration. With this as a touchstone, we break down the overriding principles for actions and decision today without renouncing consideration to the long-term consequences. A key question in this process is increasingly the one we started with: how our own generation can make credible decisions that will have repercussions far into the future. For this reason, it is motivated here to bring to the fore the most important general principles.

1.3 From principles to strategy

There exists a number of different formulations, both general and more specific, with differing focuses. IAEA (the International Atomic Energy Agency) stipulates in its Principles of Radioactive Waste Management (Safety Series No. 111:F, 1996) in the section *Protection of future generations* that "Radioactive waste shall be managed in such a way that predicted impacts on the health of future generations will not be greater than relevant levels of impact that are acceptable today". Under the *heading "Burdens on future generations"* it states "Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations". Emphasis here is on the task of minimising the risks and burdens that are transferred to future generations. In this case, the principle of intergenerational equity, as is evident in the comments, the generation that enjoys the benefits also bears the main responsibility for creating a safe final disposal system. Distributing the responsibility equally among generations is out of the question.

The above-mentioned OECD document comes to basically the same conclusion when it uses the intergenerational equity principle as an ethical base for selecting a strategy for long-term management of nuclear waste. Even if the analysis of the difficult

ethical problem of intergenerational equity includes the concept that "each generation leaves a heritage to posterity, involving a mix of burdens and benefits", (p 12), the direction is clear. From the standpoint of the responsibility of the present generation, the principle of intergenerational equity leads to a choice of strategy whose main purpose is to "minimize the resource and risk burdens passed to future generations by the current generations wich produce the wastes" (p 12).

Both the IAEA principles and the OECD document are clearly in line with the generally accepted interpretation of the Brundtland commission's concept of sustainable development as an ethical principle, in *Our Common Future* (p 43) formulated with the words to meet "the needs of the present without compromising the ability of future generations to meet their own needs". By referring to other pertinent texts such as the Rio Declaration on Environment and Development, 1992, this document has been interpreted in terms of intergenerational equity to mean the minimisation of the transfer of direct and indirect burdens to future generations (see e.g., Hans Berkhout in the OECD seminar report *Environmental and Ethical Aspects of Long-lived Radioactive Waste Disposal*, 1995, p 123). This pertains particularly to "irreducible burden" on which the precautionary principle established in the Rio Declaration should be applied. According to this principle, early efforts to reduce harmful effects on the environment are preferable and irreversible effects should be avoided completely. Naturally, in a number of cases, radioactive contamination is an irreversable environmental effect.

According to the principles mentioned, intergenerational equity is primarily a matter of an equitable *distribution of risks and burdens between generations* so that each generation tries to bear the consequences of the risks and burdens it has generated, or attempts to find ways of compensating future generations.

There are, however, several examples of sets of principles that offer an expanded interpretation of intergenerational equity, such as the contribution of Bayard L. Catron to the above-mentioned OECD seminar report (p 134). In a reformulation of the Brundtland commission report, the main principle states that *"No generation*

should (needlessly) deprive its successors of the opportunity to enjoy a quality of life equivalent to its own". The interpretation of quality of life in this principle is decisive. Catron claims that the formulation is such that it establishes an *equal opportunity principle* which does not focus exclusively on foreseeable risks but also takes into account resources and benefits. This assumes that consideration will be taken to future generations' options and freedom of action. Risks and benefits cannot be completely separated and a strict time limit cannot either be drawn between generations in regard to managing the risks and benefits that make up the legacy that is always a blend of risks and benefits and that, in this inseparable blend, transfers the possibilities for development to future generations.

In the general principles with which we have dealt, it is assumed, regardless of approach, that today's generation bears the responsibility for future generations and thereby for the nuclear waste that we produce today. Both approaches encounter great difficulties when the principles are to be converted into action, and when a concrete attempt is made to balance the risks and benefits between generations according to the principle of intergenerational equity. Various methods for cost/benefit analysis or discounting the costs have been tested but for the most part rejected as being untenable in the long term and in regard to people's lives and health in the future. (See, e.g., Berkhof p 118 and Catron p 130 in the OECD seminar report and the OECD document p 17). It is not possible to extrapolate all necessary factors as far into the future as is necessary. Even if one could supplement the general principle of intergenerational equity with a principle for applying compensation for conceivable risks, it would not be possible to calculate the value of this compensation over a greater timespan.

Even those who have attempted to view the concept of sustainability and the supplementary precautionary principle and "the polluter pays" principle, as a way of escaping from the dead-end that the cost/benefit analysis has shown itself to be, encounter difficulties when they attempt to draw concrete conclusions on the prevalent main alternative of a geological repository. On one hand, it is apparent that most of the burdens are reduced to a minimum –

e. g. is the financial burden assumed by the current or next generation. On the other hand, a sealed final repository represents an irreversible change to the environment and should therefore be avoided. Furthermore, such a repository, designed without allowing for continuing institutional control, would limit the freedom of coming generations to decide how they would like to manage the waste, and would also in the long-term impede access to an as yet unutilised resource. This puts increasing focus on the possibility of retrieving the waste in the future as a necessary issue to study and to take into account. This possibility is, besides, also integrated into IAEA's principles of radioactive waste management, principle 5 regarding the burdens on future generations.

Even when attempts have been made to apply the concept of sustainability to other alternatives, it has become apparent that this does not lead to any unequivocal results for the choice of one strategy or the other. We are faced with the task of balancing between the advantages of a certain strategy and the price that future generations will have to pay for this choice. The question brought to the fore is the degree of certainty with which we can weigh the pros and cons of the factors regulating the way in which the principle of equity between generations should be applied, that is, equity for both the generation of today and those of tomorrow. It is not only a question of trying to strike a balance between benefits and burdens/risks for generations far in the future but between our generation and the nextcoming generation as well.

Let us see if anything can be picked up from those who have attempted to arrive at more specific principles. An example of this is the set of principles that were developed by a working group under the auspices of The National Academy of Public Administration, NAPA, in the USA and the US Department of Energy, DOE (OECD seminar report, p 134). The overriding concept is the obligation to future generations, to which the relationship is defined by the statement *"Every generation is the trustee for those that follow"*. If we examine the subsequent principles we find demands for giving the present and near future precedence, with the restriction that it must be a question of *vital interests or basic needs*. Consequently, the precedence that the

present holds diminishes as soon as the question of irreversible damage or the threat of catastrophic effects arises. However, long-term hypothetical hazards have lower priority than near-term concrete hazards.

The principles as such are not the most interesting point since they present us with a long line of definition problems in regard to vital interests and basic needs. The matter of greatest interest is rather the reason for the precedence for the present time on which the principles are based: the difficulty in making credible and legitimate calculations of the conceivable effects into the distant future, which are dependent on our limitations as to *uncertainty* about the future, when it comes to balancing between the needs of today and alternative needs in the distant future. The literature that has lead to the NAPA/DOE principles seems to calculate on a breakpoint some 100-150 years in the future. The significance of this is that ethical considerations regarding this period differ from those pertaining to the more distant future. This is justified on the theory that during such a timespan, we can, with some degree of certainty, assume that the most immediate future generations will be similar enough to us to allow us to make credible assumptions about their priorities and values. There is, of course, no clear-cut formula or limit here, but we have nonetheless been given an indication about a means of delimiting the basic problem dealt with in this article. First, however, let us examine the essential question of the problems of the uncertainties of a long perspective of time.

1.4 The chronological scope of uncertainty

When KASAM's multidisciplinary seminar on *Ethical Action in the Face of Uncertainty* in 1987 analysed the key concept for the seminar, *uncertainty*, work was carried out on different types of uncertainty in relation to varying timespans: the human timespan, the societal timespan, the biological timespan and the geological timespan. Man is, in certain respects, remarkably constant over

time. This constancy is tempered by certain inherent limitations or imperfections for which reason we must always include the risk for human error as well as for inadequate knowledge. These limitations characterise all systems created by people. Naturally, these comprise a lasting uncertainty factor whose effects can only be validated after the fact. Human constancy is, paradoxically, a source of unforeseeable uncertainty.

Moving on to *society*, experience has shown that we are dealing with a high degree of uncertainty and that predictions about future societies, in any true sense of the word, are impossible. Society is no more secure than the stabilising factors that it is able to create within itself in the form of institutions and the transference of knowledge and values. However, this condition is not necessarily exclusively negative. As stated at the seminar in 1987, security in societal development can only be achieved at the expense of inhibited development, where possibilities for renewal are stifled and openness is replaced by restraints and rigorous surveillance.

If instead, we view time in terms of the chronology of *biosphere* or *geology* the concept of time changes. Geological time is so radically different that when considering changes in bedrock we are forced to contemplate a timespan that surpasses the human capacity for comprehension. Determining certainty/uncertainty thereby takes on a totally new dimension of time, more comparable to the half-life of the radioactivity in nuclear fuel, and which includes the demand that nuclear waste be isolated from the biosphere for a period of time that far exceeds known human history. For this reason, as was stated in KASAM's report of 1995 *Nuclear Waste – The State of Knowledge* (p 95), "It is obvious that those responsible for the final disposal of (used) nuclear fuel are looking for the most unchanging environment at disposal for a repository of the fuel", or geological disposal.

The time perspective for uncertainty is also quite different, which does not mean that uncertainty is no longer an issue. Even measured in geological terms, no statements on certainty can be made other than those encompassing risks and probabilities. This different geological time scale can explain why safety regulations

for waste management that extend over 10,000 years or more have considered it feasible to establish the goal *that human health must be protected for the length of time required by radioactive waste, according to today's norms.* The geological stability that we can count on over extremely long periods of time forms the basis for the formulation of the goal, according to Andrew C. Kadak in his article *An intergenerational approach to high-level waste disposal (Nuclear News* July 1997). It is also the determining factor for today's international consensus on the advantages of disposing of high-level waste in deep and stable geological formations, as is described in the OECD document. There is no doubt as to the goal, partly because we have reasonably certain knowledge on the stability of the bedrock and partly because we should be safe in assuming that the people of tomorrow will have the same level of tolerance for radioactivity that we have today.

If we examine the international discussion on the certainty/uncertainty of varying periods of time, we can also make the interesting observation that we use the relative predictability of geological time to *nullify* the uncertainty of other time spans. We need not worry about our inability to, for example, predict the stability of society and the short-term uncertainty that this represents, on the condition that we focus our efforts on designing a geological repository with the intention of fulfilling the long-term goal of, within the framework of naturally occurring radioactivity, ensuring the same protection for future generations that we have today.

Yet, we are confronted here by a central problem, which Kadak mentioned in the article referred to above, described as a *'jump-by-jump' credibility over time*. The confidence that we have in the bedrock and its properties over extremely long periods of time, based on geological facts, as the safest possible place for the technological design of a disposal system, is seen as a guarantee in the present for our future ability to fulfil the goals, about which uncertainty, however, increases the farther removed we become from the present. The problem is the time interval between the decision itself and the design of the disposal system on the one

hand and, on the other, the opportunity to evaluate if the safety regulations, which are based on the obligations between generations to protect future generations according to today's norms, can also be met. Can a generation that in any way attempts to retain its credibility make promises, whose trustworthiness is based on calculations on the future, either in terms of the properties of the bedrock and/or the durability of the design of the disposal system? Have we underestimated the problem regarding the timespan and consequently placed an undue burden of future commitments on todayís generation when we expand them to promises that reach so far into the future that any calculations on the conceivable results must contain a number of uncertainties? If so, is there a credible way to bridge this without waiving the responsibility that our generation has for the waste we produce? Is it perhaps a basic misapprehension that in the binding promises and safety calculations we have made we have extended ourselves much too far into the future?

1.5 A chain of generations

Both the international and Swedish debates and handling of the nuclear waste problem indicate an interesting shift, which can also be clearly seen in the OECD document from 1995. Attention has been focused more and more on the decision-making process and its credibility, with the scope that today's decisions and actions will have far into the future. The shift cannot be explained solely by the results of continuing research and technical developments, which have led to suppositions on a gradual process of realisation. Factors such as the intensifying ethical debate and the need for a democratic foundation for the decisions that must be made regarding the choice of system and site selection are at least as important. The emphasis seems to have shifted from guarantees of reaching goals for intergenerational equity in the distant future to a question *of how we can make credible decisions today without waiving our obligations to future generations, while at the same time not promising more than we can deliver.*

One essential question in this perspective is how we manage the tension between the democratic demands for credibility and our obligations for the future whose consequences we cannot fully comprehend. Lars Ingelstam provided an important contribution toward clarifying this problem in his lecture on *Accelerated Progress and Social Complexity – Reflexions on the Limits of Technology* at The Royal Swedish Academy of Engineering Sciences' conference on transmutation technology on October 24, 1997. Ingelstam's starting point was the necessity of trying to understand complex technical systems in their cultural and social contexts. In most cases, we should refer to these as socio-technical systems. The problem of understanding is not only scientific but is also societal and democratic and is in this dimension a question of confidence and credibility. This question gains added importance when socio-technical systems are planned to function for a protracted period of time. Radioactive waste is a case in point but far from the only one.

According to Ingelstam, there is "an indisputable link between comprehensibility and democracy. The democratic form av government rests on two assumptions: that the average citizen can make up his own mind on questions that concern him and his future, and that he can foresee the consequences of his actions sufficiently well to take responsibility for them". It is self-evident that the comprehensibility and the corresponding confidence will be particularly difficult to reach in a system requiring a high level of technical, specialised knowledge that is only accessible to experts and where the interval of time between design and the opportunity to discover if it functions as intended or is a failure, is long. The long period of time also makes it impossible to demonstrate the results.

The question, Ingelstam argues, then becomes one of whether or not it is possible to bridge the time interval, or discover a link between the present and the future so that the comprehensibility and credibility can be preserved even for complex socio-technical systems designed to function for an extended period of time where we have no possibility to demonstrate that they will function as planned on the basis of the demands we make for long-term safety.

Ingelstam claims that this link is *institutional constancy*, by which he means the necessity to build in control mechanisms in society's institutions to continuously test to see if promised results are achieved. This also assumes qualities that enable us to trust in the fulfilment of responsibilities that transcend time, individuals and generations.

Therefore, with the previous statement in section 1.4 – The temporal scope of uncertainty – the attention that has been focused on the internal stabilising factors a society "is able to create in the form of institutions, and forms of knowledge and values" is equally as essential as a direction toward designing technical systems in regard to the demand for long-term safety. At this point, however, we have limited knowledge about how to design institutional relationships that preserve the quality of future action, while preserving the open, democratic society. At the same time, this is the only avenue open to us if we are to maintain democratic credibility in the present while adhering to our commitments to future generations.

We can, however, fall back on a way of thinking which – in the process of transferring the principles of equity among generations to credible concrete actions in the present for nuclear waste disposal – discovered a concept that adequately meets Lars Ingelstam's term of "institutional constancy". This concept indicates that the present and the future are linked by people and institutions that act as conveyors of obligations and the potential for development from generation to generation: *the rolling present.* This term has been coined in an attempt to deal with the dilemma with which we are confronted, based on the realisation of the long-term effects of our actions. On one hand, we cannot renounce our responsibility for these actions. On the other hand, we cannot, at the same time, refrain from a responsibility to fulfil our basic obligations to the current generation in terms of the potential for comprehensibility that is basic to a functioning democracy and its accompanying credibility. A prerequisite for this is a basis for decision-making that enables us to make a reasonable assessment of the consequences.

Inevitably in this situation, we are confronted by a *time limit*. This limit is set by the human capacity to imagine – anything exceeding the bounds of human measurement cannot be comprehended by humans. The limit is also imposed by the fact that the uncertainties of our base of knowledge, which include the capacity to determine the durability of the system's technical design, increase as a function of the increasing timespan-perspective . The degree of credibility in the material used as a basis for decision-making diminishes also over the course of time. Science too, has its limits of credibility. This means that our capacity to assume responsibility changes with time. *In other words, our moral responsibility diminishes on a sliding scale over the course of time*.

The "rolling present" concept takes this into account by assuming a successive chain of decisions and tests over time and by building into the decision-making process the capacity to, examine, on the one hand, previous decisions, identify significant uncertainties that require additional research, and on the other hand, make design improvements by implementing newly acquired knowledge and experience. The current generation has the responsibility to provide the next generation with the skills, resources and capacity to deal with the problems passed on by the generation of today. The next generation has the same obligation to the coming generations. New generations evaluate the policies of their predecessors by using new information and their own values and priorities.

A process such as this, which acts as a flow between generations, is also in step with the conditions for technical development, or what is often referred to in available documents as "the technical design period". Making a credible assessment of safety requires a development process that allows time for testing, research and, in cases of uncertainties, design improvements, etc. On the one hand, considering the long timespan, we cannot bind ourselves technologically. On the other hand, we must have clear design objectives. Therefore, we must leave open *when* and *if* the 'rolling present' process reaches the point where the disposal method that is considered optimal today, and which is our

responsibility to develop, becomes a final repository or, alternatively, that what is considered to be waste today becomes transformed into a resource.

This open approach to different future possibilities is already part of the conceptual preconditions of the 'rolling present' concept. These preconditions go back to the way in which we, in the present, conceive of what equity between generations will demand of the current generation. This brings us back to the concepts behind KASAM's position in 1987. When, in his classic book from 1971 *A Theory of Justice*, the philosopher John Rawls attempts to establish principles for equity, he uses a moral filter that he calls *the veil of ignorance* (p 136). He proposes that we should imagine a situation in which we must make a decision on what the principles for a just society are without knowing exactly who we will be and where we will live in society.

Rawls applies the same thinking to our obligations to coming generations (p 284 ff, see also K.S. Shrader-Frechette, *Burying Uncertainty*, 1993, p 191). We do not know to which generation we belong, nor do we know what society will look like. Therefore, we cannot make any other credible suppositions about the people and society of the future and their priorities than we make about our society and ourselves. Not surprisingly, Rawls comes to the conclusion that "every sensible person – without knowing his generation, social class, level of intelligence, etc – accepts the principle of just intergenerational distribution of risks, resources and assets". In attempting to specify what this means, he assumes the overriding principles of equity in the distribution of opportunities and establishes a tripartite task for today's generation: 1) To preserve the gains of our culture and civilisation for posterity; 2) To maintain our just institutions intact; 3) To pass on to future generations a greater capital, in the form of more knowledge and better developed technology than we ourselves received from previous generations. This should compensate for what we have consumed and pave the way to a better life in a society which is more just than today's. In other words, we cannot predict conceivable damage nor the advantages of specific actions in the distant future. The best we can hope for is to provide for posterity with what we

have today and at the same time preserve as much freedom of action as possible for future generations.

Rawls mental experiment to establish today's obligations toward future generations corresponds well to the concept of a "rolling present" and its notion of a transfer of responsibility along a chain of generations. The emphasis is on the immediate responsibility between one generation and the next.

1.6 Conclusions

An attempt to draw preliminary conclusions might lead to the following:

1) In terms of responsibility, it is not credible for the current generation, with the knowledge it has access to of the long-term consequences, to remain passive in anticipation of progress or to wait for the time when today's uncertainties become "certain". We cannot mortgage possible future advances just as we cannot base our decisions on hypothetical suppositions. In all likelihood, we will not either be able to cover all expenses – this assumes, among other things, economic stability. As our research and development efforts continue, it is incumbent on us to seek the optimal solution today in order to gradually demonstrate the durability of the technical design in its interaction with the characteristics of the bedrock.

2) The 'optimal solution' that we choose today, seen against the background of the thorough assessment of various alternatives, must both be a flexible solution and also provide coming generations with ample freedom of action. The transition to the use of the concept *deep disposal* instead of *final disposal* can be seen in a growing number of current documents and in doing so appears valid.

3) The decision that we can make today and which appears to be unavoidable considering the responsibility that lies with today's generation is not a final one but is rather a link in a longer chain of decisions with a built-in capacity for evaluation. However, today's decisions must be made with the knowledge now available to

ensure reasonable safety of the repository in the long term. We select a disposal *as if* it were to be a final repository, but leave it to coming generations to decide whether it will be that in the future. We thereby admit that there is a *cutoff point in time* after which the nature of our responsibility changes.

4) If we regard the relationship between generations as a chain of responsibility as an unavoidable part of our insight on the basically unforeseeable effects of our actions thousands of years from now, we need to focus, in a completely different manner than has been the case up till now, on the manner in which we promote stabilising factors in society in the form of institutions and the intergenerational transfer of knowledge, values and forms of obligation to assume responsibility. We cannot claim to take full responsibility for a future that is not within our grasp in terms of imagination, knowledge or technical design. In this sense, *credible responsibility is shrinking over the course of time*. Yet, the full ramifications of this have to be expanded, since responsibility nevertheless remains with us in this generation.

_____

Note:

The concept *generation* is difficult to define and numerous definitions and attempts have been made to define it. The expression "today's generation" in the article includes all living "generations". When we refer to the relationship between today's generation and future generations, it is assumed that the generations are intertwined with no clear demarcation. Development functions as an intergenerational flow of risks, burdens, assets and opportunities for development.

References

Bayard L. Catron, Lawrence G. Boyer, Jennifer Grund, John Hartung, *The Problems of Intergenerational Equity*, C. Richard Cothern, ed, *Handbook for Environmental Risk Decision Making: Values, Perceptions, and Ethics*, Chelsea, MI: Lewis Publishers, 1995

Environmental and Ethical Aspects of Long-Lived Radioactive Waste Disposal. Proceeding of an International Workshop organised by the Nuclear Agency in co-operation with the Environment Directorate, Paris, September 1-2, 1994, OECD DOCUMENTS, 1995.

Ethical Aspects of Nuclear Waste. Some salient points discussed at a seminar on Ethicl Act ion in the Face of Uncertainty in Stockholm, Sweden, september 8–9, 1987. SKN report 29, KASAM/SKN, April 1988.

Lars Ingelstam, *Accelerated Progress and Social Complexity. Reflexions on the Limits of Technology in "Why Research on Accelerator-driven Transmutation Technology?" Proceedings from an international conference arranged by the Royal Swedish Academy of Engineering Sciences (IVA), in 1997.*

Hans Jonas, *The Imperative of Responsibility – In Search of an Ethics for the Technological Age*. Translated by Hans Jonas with the Collaboration of Daid Herr, The University of Chicago Press, 1984.

Andrew C. Kadak, *An Intergenerational Approach to High-level Waste Disposal*, Nuclear News, July 1997.

Osäkerhet och beslut. (Uncertainty and Decisions).A report from a seminar on decision-making in the face of uncertainty regarding nuclear waste disposal, at Hässelby castle, April 4-6, 1990. SKN report 45, Statens kärnbränslenämnd/KASAM, February 1991.

John Rawls, *A Theory of Justice*, Harvard University Press, 1971.

K.S. Shrader-Frechette, *Burying Uncertainty*, University of California Press, 1993.

The Environmental and Ethical Basis of Geological Disposal. A collective opinion of the NEA Radioactive Waste Management Committee. OECD, 1995.

The Principles of Radioactive Waste Management, Safety Series No. 111-f, International Atomic Energy Agency, Vienna, 1995.

Our Common Future. The World Commission on Environment and Development, Oxford University Press 1987.

KASAM reports.

2 Is there a clear decision-making process?

How to manage the spent nuclear fuel and radioactive waste is a complex issue with a number of scientific, technical, ethical and political aspects. The decision-making process extends over several decades, comprises a chain of many vital decisions and involves a number of actors with often divergent interests. The complex and controversial nature of the issue increases the demands for a transparent and open decision-making process. In March 1997, KASAM, in co-operation with the National Co-ordinator for Nuclear Waste Disposal, organised a seminar in Umeå on the decision-making process. This seminar was attended by a wide range of interested parties, including representatives from the Swedish Nuclear Fuel and Waste Management Co (SKB), government authorities, municipalities and environmental organisations. The seminar has been documented in the report "Kärnavfall och Beslut" (Nuclear Waste and Decisions), SOU 1997:180. The report is available in Swedish only.

The original version in Swedish of this chapter was finalised in May 1998. New developments after that (important changes in the legislation from 1 January 1999, SKB´s presentation of its 1998 RD&D programme in September 1998, review statements on this programme by concerned authorities and others [including KASAM] and a pending Government decision on SKB´s RD&D programme 98) means that facts and arguments in this chapter to a large extent are out of date. For this reason a translation to English of this chapter is not provided here.

3 Radioactive releases and radioactive waste from non-nuclear energy production

3.1 Introduction

All energy production* has an impact on the environment. One example of this type of impact is the release of radioactive substances and the ensuing exposure to radiation of staff, the public and the surroundings. In regard to the public, it is primarily the consequences of major accidents at reactors that are of interest. Even if the probability of an accident of this type occurring is extremely low, such accidents can result in high doses of radiation to large groups of people. Under normal circumstances, small groups of employees at nuclear facilities or the people handling the nuclear waste generated there may be subjected to doses of radiation equivalent to naturally occurring background radiation (1 mSv/year). Certain individuals may receive doses of up to 10 times this amount. From the point of view of radiation protection, the increased use of e.g. wood chips and peat has been made more complicated since these materials today are contaminated to varying degrees by radioactive fallout, primarily from the Chernobyl accident. Extracting oil also affects the radiation environment of employees and the public. In the production of energy, radioactive substances and ionising radiation are also

* In reality: energy conversion

sometimes used to check processes, levels and the degree of extraction in, for example, the oil industry.

The purpose of this chapter is to report facts and to provide a basis for the ongoing discussion of the radiation effects of various types of energy production. Up until now, nuclear releases and waste have been at the centre of this discussion. Is it true, as has sometimes been stated, that more radioactive substances in the fuel are released when burning biofuels than by the production of nuclear power?

From a radiological viewpoint, a differentiation can be made between two types of energy production processes:

- Ones in which already existent radioactive substances in the fuel are enriched by combustion (coal, oil, gas, biofuels), often leading to the release of small amounts of radioactivity into the environment.
- Ones where new radioactive substances are created (nuclear power) and are contained in waste or releases.

It should be pointed out in this context that radiation and radioactive substances have existed in man's surroundings throughout history and will continue to do so in the future. In addition to cosmic radiation, we are exposed to a number of different natural radioactive substances that are found in the soil, food, building materials, fuels, etc.

To get a complete picture of the environmental effects of different types of energy production, the entire impact on the environment must be determined, i.e. not only those aspects directly connected with ionising radiation and radioactive substances. In most cases, radiation causes only a small part of the impact. There are a large number of organic and inorganic substances, including heavy metals, which have known harmful effects on both people and the environment. Some are broken down in time while others retain their toxicity longer than the most long-lived radioactive substances. A comparison with substances such as arsenic, lead, beryllium, cadmium, chrome and nickel, all of which are released during the combustion of coal or from mining, offers a perspective on questions pertaining to the

management of extremely long-lived radioactive waste. A comparison has also been made (Christensen et al, 1994) of the total impact of different types of energy production. These types of comparisons will not be made in this chapter since its sole purpose is to provide a basis for comparison with radiological impact and to report on currently available means of assessing the impact of radioactive waste in different areas.

3.2 Sweden's energy use

Sweden's total annual energy use is approximately 350 TWh. An overview of each type of energy's share of the total is shown in table 3.1. The table does not differentiate as to how the energy was used (heating, driving, industrial or household uses). The summary shows the continuing dominant role of oil (40% of energy use) and that hydropower, nuclear power and biofuels each account for 17-19%. The share of coal and gas is approximately 6%. If only electrical energy is taken into consideration, which accounts for almost 40% of the total energy use (1993-96) or approximately 140 TWh, the proportions are: nuclear energy 48%, hydropower 45%.These figures are often quoted and discussed in the mass media.

Table 3.1: Energy use in Sweden has been around 350 TWh/year (Statistics Sweden 1994, table 116, page 103; Statistics Sweden 1995, table 117, page 103; Statistics Sweden 1996, table 118, page 107).

Type of energy/source	**Energy use (TWh)**			**Share (%)**
	1993	**1994**	**1995**	**1993-1995**
Petroleum products	135	141	143	39.8
Hydropower	73	58	68	18.9
Nuclear power	59	70	67	18.6
Wood, sulphate and sulphite lyes, other. Biofuels, refuse and peat	58	59	60	16.8
Coal and coke	12	13	13	3.6
Natural gas and coal gas	8	8	8	2.3
Total	345	349	359	100

The energy production achieved through combustion is compiled in table 3.2. Combustion causes both the enrichment of radioactive substances from the fuel to ash products and the release of radioactive substances.

Table 3.2: Energy produced by combustion.

Energy source	**Energy use (TWh)**			
	1993	**1994**	**1995**	**1996**
Oil	75	85	84	88
Biofuels and peat	77	76	80	84
Coal and coke	27	28	28	31
Total	165	178	181	191

3.3 Nuclear energy

It is not our intention in this chapter to report on the details of the radioactive releases from nuclear energy production or on the exposure to people and the environment. Instead, we will summarise the radiation doses to people caused by nuclear power production.

Since the first Swedish nuclear power plant was started up in 1972 for large-scale commercial electricity generation, substantial data have been compiled on releases and radiation doses to both employees and to people living in the vicinity of nuclear power plants. Table 3.3 summarises some of these data.

Table 3.3: Estimated yearly doses (µSv/year) from the release of radioactive substances into water and air from Swedish nuclear power plants, to "critical groups" in the area (source - Swedish Radiation Protection Institute (SSI), 1991-1997). The share of ^{14}C and the other radionuclides released by nuclear power plants are reported separately. See the glossary for the definition of "critical group". Please note that the unit used in this table is 1 µSv/year = 1/1000 mSv/year.

Nuclear power plant		Estimated yearly doses to members of the "the critical group" (µSv)							
		1989	1990	1991	1992	1993	1994	1995	1996
Barsebäck	other	1,86	0,29	0,86	0,56	0,15	0,09	0,17	0,26
	^{14}C	0,92	0,92	0,96	0,30	0,32	0,6	0,6	0,6
Forsmark	other	0,87	0,48	0,50	0,26	0,35	0,10	0,06	0,08
	^{14}C	0,57	0,57	0,62	0,28	0,29	0,4	0,4	0,4
Oskarshamn	other	2,90	2,24	1,72	0,90	0,75	0,44	0,42	0,36
	^{14}C	0,45	0,45	0,49	0,17	0,15	0,2	0,2	0,2
Ringhals	other	1,59	2,38	1,39	3,4	19	36	24	10
	^{14}C	11,0	11,0	11,4	8,5	8,6	6,7	6,7	6,7

The dose contributions from ^{14}C are based on theoretical estimates of the size of ^{14}C releases, while the contributions from the other radionuclides are based on measurements of actual releases. SSI has set of a limit of 0.1 mSv (100µSv) per year as a goal for the critical group. As a comparison, the average dose to a Swede from naturally occurring background radiation (cosmic radiation, naturally radioactive ^{40}K in the body and external radiation from the soil and buildings) is approximately 1 mSv/ year. The radiation dose from daughters of radon in the lungs and bronchial passages is considered to correspond to a whole-body dose of approximately 2 mSv/year. This contribution can vary greatly from place to place. The table shows that radiation from all of the plants combined has been under – in most cases well under – this

limit. This is compared to the high readings from Ringhals which were caused by fuel failure in unit 1 combined with relatively short retention times in the offgas system. This, in turn, is due to the fact that Ringhals 1 belongs to the oldest generation of Swedish reactors and has an older offgas system.

Table 3.4 shows the total collective dose to personnel involved in nuclear activities. The number of employees during the period 1992-96 was just over 6,000. Their average dose during the period varied between 2.9 and 4.3 mSv/year with individual maximum readings of up to 50 mSv/year.

Table 3.4 shows that the employees' contribution to the collective dose is much higher than the collective dose to the public, as a result of releases from nuclear power plants.

Table 3.4: Swedish nuclear power's annual contribution to the collective dose, divided among personnel, people living nearby and others.

	Collective dose*, (manSv)				
	1992	1993	1994	1995	1996
Personnel	21.3	28.4	18.1	19.1	22.9
Public: local and regional	0.09	0.32	0.53	0.32	0.18
Public: global (^{14}C)	34	34	41	40	41

The values shown in table 3.4 relate to an energy production of approximately 65 TWh (or 7.4 GW years). The Swedish limit for the collective dose contribution from nuclear power plant operation is 5 manSv/year/installed GW (electricity) for radiation doses to the public. This is the equivalent of 37 manSv/year for the current level of Swedish nuclear power production. The estimated value in table 3.4 (Public: local and regional + global) agrees with this limit.

* See the glossary

One interesting point is to see how the Swedish data correlates to international figures. For details, please refer to the detailed examination of the UN's Scientific Committee UNSCEAR (1993), which is summarised in the table 3.5 below.

Table 3.5: The estimated total dose contribution from nuclear power production to the public, normalised for a production level of 1 GW/year of electrical energy according to the UN's Scientific Committee UNSCEAR (1993). When converted to Swedish nuclear power production (65 TWh), this would mean a contribution as shown in the right-hand column.

Source	**Collective dose**	
	manSv per Wyr(el)	**(manSv per 65 TWh)**
Local and regional components		
Mining and uranium processing	1.5	(11)
Fuel fabrication	0.003	(0.02)
Reactor operation		
atmosphere	1.3	(9.6)
water	0.04	(0.3)
Reprocessing		
atmosphere	0.05	(0.4)
water	0.2	(1)
Transport	0.1	(0.7)
Total	**3**	**(22)**
Global components (incl. solid waste)		
Mining and pulverising waste prod. (^{222}Rn releases for 10 000 yrs.)	150	(1100)
Reactor operation		
low-level waste	0.00005	(0.0004)
intermed.-level waste	0.5	(4)
Reprocessing of solid waste	0.05	(0.4)
Globally spread radionuclides (^{14}C etc)	50	(400)
Total	**200**	**(1500)**

(1GW year = 8.76 TWh)

The table also shows that other parts of the nuclear fuel cycle than those discussed above for Sweden result in a dose

contribution to man and the environment. The predominant contribution is estimated to come from the globally increased level of radon resulting from uranium mining and the similarly increased levels of ^{14}C resulting from reactor operation as well as fuel reprocessing and the disposal of waste. The estimate of the extent of these contributions is, of course, very uncertain. Radon releases of this type can also occur e.g. from coal mining. With regard to directly comparable values, if the international average values were applied, one would expect the current level of Swedish reactor operation (65 TWh/year) to result in an annual collective dose of approximately 10 manSv. The estimated value in table 3.4 (public: local and regional) for Sweden is 30 times lower. Regarding the more long-term affects of globally dispersed radionuclides, it can be assumed from the value of 400 manSv calculated by UNSCEAR, that 1/3 or 130 manSv would comprise ^{14}C contributions. The Swedish estimates do not exceed 40 mSv (table 3.4).

3.4 Geothermal energy

Geothermal energy is stored in the form of heat in bedrock or is generated by radioactive decay at the centre of the Earth. To harness geothermal energy, hot water or steam is extracted from deep boreholes. People have used hot groundwater for bathing and heating for thousands of years. Geothermal energy has been used to produce electricity for approximately 100 years. The occurrence of radioactive substances in hot springs has been known since 1911 (Whitehead, 1980). Today, geothermal energy is used primarily in Iceland, Italy, Japan, New Zealand, Russia and the USA. It is also used on a smaller scale in other countries e.g. Sweden. Nearly 50% of the heat supplied to Lund’s district heating system can be attributed to geothermal energy.

Radioactive substances in uranium’s decay chain dominate the activity in geothermal flows. From the point of view of radiation protection, the greatest interest has been focused on ^{222}Rn which

dissolves in water and which disappears into the air during distribution to users. In Iceland, 2-10 kBq/m^3 (2-10 Bq/litre) ^{222}Rn has been found in the water from hot springs (NKA, 1989). This can be compared with the Swedish limit of 100 Bq/litre for water from municipal water works or private wells to be considered potable (National Food Administration, 1997). The average figure for radon releases is 150 TBq/GWyr and the collective effective dose caused by this is estimated at 2 manSv/GWyr. The annual dose per person 1 kilometre from a plant producing 100 MW of thermal energy is approximately 0.01 mSv. Radiation doses to personnel at the deep boreholes can be significant unless the facility is equipped with good ventilation.

Solid radioactive waste only occurs on a small scale in the form of material transported up with water from the bedrock.

3.5 Hydropower

Hydropower does not lead to any releases of radioactivity to the environment and generates no radioactive waste. The activity does not affect the human radiation environment more than traditional construction work and indoor or underground work. Anyone working in the underground generator facilities at hydropower plants can be exposed to e.g. increased concentrations of radon and daughters of radon. The collective dose for Norwegian hydropower workers has been calculated to be approximately 2 manSv/year. Approximately 110 TWh of electricity is generated annually (1994), leading to 0.02 manSv/TWh or 0.2 manSv/GWyr.

3.6 Wind power

Electricity produced by wind power does not lead to any radioactive releases and generates no radioactive waste other than that which arises from material extracted and used for producing components and when components are scrapped.

3.7 Solar power

Solar radiation generated by nuclear reactions at the core of the sun are crucial for all life on Earth, the water cycle and for energy supply. Directly utilising solar radiation in large solar power plants still poses problems. The possibility of using solar energy in the future to produce hydrogen gas is being discussed. Solar panels and solar cells are used today on a small scale and do not affect the radiation environment.

3.8 Burning coal

Coal in the form of bituminous coal and lignite are the predominant fuels for the world's production of energy. On the other hand, coal is used only for approximately 4% of the energy produced in Sweden. The average concentration of naturally occurring radioactive substances in coal is lower than in the Earth's crust in general but can vary greatly from one coal mine to another. Uranium concentrations of between 0.1 and 100 µg/g of coal with an average figure slightly under 2 µg/g have been reported from the USA. Measured concentrations of radioactivity are shown in table 3.6 below.

Table 3.6: (from Martin et al., 1997). In bituminous coal, the various products in uranium's (U) and thorium's (Th) decay chains are in radioactive equilibrium. The U and Th levels in individual coal samples can vary widely depending on the origin of the sample. (K= potassium)

Area	**Concentrations of radioactivity (Bq/kg)**		
	^{238}U	**^{232}Th**	**^{40}K**
EU	30(7-185)	15(3-22)	130(1-300)
USA	18(1-540)	21(1-230)	55(26-93)
Japan/Australia	12	13	72
China	36	30	104
Global	**20**	**20**	**50**

There are isolated examples of coal mines where concentrations of radioactivity have been measured that are 100 times higher than the highest value in the table above.

Coal is burned in the form of a fine-grained powder in power plants. The radionuclides that are supplied to the power plants are removed in four different ways, as:

- bottom ash that is deposited at the bottom of the furnace;
- fly ash that follows the flue gases and is separated in filtering devices;
- The part of the fly ash that passes through the filter and is released into the atmosphere;
- gases that pass through the filter.

One effect of combustion is concentration of the radionuclides in the fuel. Of the coal that was originally contained in the fuel, only 5-20% remains after combustion, in the form of ash that contains practically all of the radioactive material that was in the fuel. The concentrations are now approximately 10 times higher than in the original fuel. Concentrations of radioactivity in the fly ash increase as the particles are fractionated, which means that the ash that is released has a higher concentration of radioactivity than that which is trapped in the filter (Mustonen and Jantunen, 1985). Large amounts of coal ash are produced annually – approximately 100 million tonnes globally. Some of this ash is used in building and construction materials while the rest is deposited in land-fills or is dumped into the ocean. Radionuclide leakage and radon releases from ash heaps have radiological consequences, both for employees and for the public. In regard to releases from stacks, both radionuclides in gaseous form and in particles that are not trapped in filters can result in a radiation dose to the public.

The proportion of bottom ash and fly ash is usually 3:1. However, up to 99% of fly ash can be separated before it is released into the atmosphere. Modern power plants have a filtering process that cleans sulphur dioxide from the flue gases before they are released into the atmosphere. This process consumes gypsum and water that could contain elevated levels of radioactive substances.

Burning coal results in waste containing higher concentrations of radionuclides from U and Th as well as ^{40}K which are generally 10 times higher and up to 100 times higher for certain radioactive substances (^{210}Pb and ^{210}Po). The type of coal used, the design of the power plant and the efficiency of the filtering system for fly ash all affect the size of the releases. Despite comprehensive studies, it is still difficult for individual power plants to predict, even approximately, the enrichment factor of the various radionuclides that are released.

The release of naturally occurring radioactive substances from the chimneys of coal-fired power plants adds slightly to the naturally occurring background levels (less than 1%). The effective dose to people living nearby is estimated to be 0.001 mSv/year for a 1000 MWh coal-fired power plant. Leakage of radionuclides from ash heaps is not seen as an appreciable problem while the use of ash in building materials has been shown to result in increased and unnecessary exposure to both residents and construction workers. One important exposure pathway is resuspended ash from landfills via the crops and vegetables grown in the area. Dose contributions as high as 0.25mSv/year have been reported to individuals in the vicinity of a waste water pond near a coal-fired power plant in the USA. Covering the pond can reduce this problem.

The dilution of radioactive ^{14}C with non-radioactive carbon that occurs when burning fossil fuels (the Suess effect) reduces the dose contribution from ^{14}C.

Regarding the use of coal, the radiological problems should not be the main topic of discussion. The risks from toxic organic compounds, heavy metals, carbon dioxide, sulphur and nitrogen oxides, etc should be given greater attention.

3.9 Burning oil

Varying concentrations of naturally occurring radioactive substances can be found in crude oil reservoirs. These and other

mineral compounds can precipitate onto the insides of pipes and containers. The dominant radioactive substances in waste products are radium and its by-products. Concentrations in these deposits are typically 100 times higher than in bedrock. Table 3.7 shows typical concentrations in high-level deposits. These values do not, however, represent the highest measurements that have been recorded. Deposits on the inside of pipes have been found to contain concentrations of radioactivity from ^{226}Ra and ^{228}Ra of up to 1MBq/kg. This means that as little as 200 hours/year spent cleaning pipes, storage tanks and pumps near these deposits can lead to an external dose of 2 mSv/year. The average figure for an employee is 1 mSv/year (Martin et al., 1997). In Norway, Kristensen (1994) found a total yearly external and internal radiation dose of approximately 0.5 mSv for personnel on land who cleaned contaminated equipment. This is considerably higher than for employees on the oil platforms.

Table 3.7: Concentrations of radioactivity in high-level deposits (1 kBq=1000 Bq)

	^{226}Ra	^{210}Pb	^{210}Po	^{228}Ra	^{228}Th	^{224}Ra
Concentrations of radioactivity (kBq/kg)	200	50	50	100	100	100

The personnel who perform the actual drilling work are also exposed to neutron and gamma radiation from compounds used to obtain information about the boreholes – borehole logging. The effective dose can amount to many mSv per year (Inskip et al., 1991; UNSCEAR, 1993).

People who work at sea are exposed to less naturally occurring background radiation than those who work on land due to lower levels of radon.

The way in which waste and releases from the oil industry are handled varies from one country to the next. Nearly 400 GBq were released from British oil platforms into the sea in 1994. A small

fraction of this was dealt with and stored on land. On Norwegian platforms, concentrations of radioactivity above 70 kBq/kg are regarded as radioactive waste and are either returned to the emptied reservoir or are stored on land. Nearly 100 tonnes of waste with an average concentration of 150-200 kBq/kg can be found in various locations in Norway. Approximately 2000 tonnes of similar waste must be handled within the EU each year.

Most oil is used in the transport sector. Emissions relating to automobiles has not been studied closely. On the other hand, there is some information pertaining to oil-fired heating and power plants, where the ash content is quite low. The amount of fly ash that is produced at an oil-fired power plant is only one-fourth the amount produced at a coal-fired plant. Since the concentrations of radioactive substances in oil are much lower, the concentrations in the ash are also low (Eisenbud and Petrow, 1964; NCRP, 9187). The airborne releases from oil-fired plants are approximately one hundredth of the amount released from a comparable coal-fired plant (USAEC, 1973; Okamoto, 1980) despite the fact that a modern coal-fired plant releases less than 1% of its total fly ash through the stack while a modern oil-fired plant releases the greater amount of its fly ash through the stack. The releases of ^{228,230,232}Th and ^{226,228}Ra from a plant that produces 1,000 MWyr of electrical energy is 1 MBq (Energy Report Series, 1985).The equivalent lung dose rate to people within a radius of 16 km from another plant has been calculated at 0.00002-0.0004 mSv/year (NCRP, 1987). The annual effective dose to an individual in a critical group will amount to 0.0001 mSv. The collective dose is estimated at 0.5 manSv/GWyr (UNSCEAR, 1993).

3.10 Burning gas

Natural gas contains up to 50 Bq/litre of radon (UNSCEAR, 1988) that has diffused into the gas from the surrounding bedrock. Thoron (^{220}Rn) can be disregarded due to its short half-life. ^{222}Rn forces its way up into the atmosphere through fissures in the

bedrock, through the ventilation or through the combustion of natural gas. Radon gas can then be breathed in by workers or the public, resulting in an internal dose contribution. Gas that is burned in electricity-producing power plants results in a collective effective dose of 3 manSv or 0.03 manSv/GWyr (UNSCEAR, 1998). The annual effective average dose to people in the USA who use gas stoves in their homes for cooking is estimated to be around 0.000004-0.00001 mSv, which means a collective dose of over 500 manSv for the population of the USA. Burning natural gas for heating of individual households leads to an effective average dose of 0.02-0.05 mSv or a collective dose contribution of more than 290 manSv (NCRP, 1987). External radiation and inhalation of ^{222}Rn are of little importance for maintenance personnel working on the natural gas grid. More research is necessary to determine how long-lived ^{222}Rn daughters are formed in different parts of the natural gas grid (Gesell, 1975). Thin layers of the ^{222}Rn daughter ^{210}Pb have been discovered on the inner surfaces of the pipes in the natural gas grid (Rogers, 1991).

3.11 Burning sludge from sewage treatment plants

Sewage treatment plants produce large amounts of sludge with a dry weight of around 20%. Swedish treatment plants have difficulty today in disposing of the sludge. In continental Europe, the sludge is burned to decrease the volume. Attempts at burning sludge have also been made in Sweden. We would like to draw attention in this matter to the high concentrations of radioactivity that may be contained in the ash. Even if we assume an enrichment factor as low as 10, the concentration of ^{137}Cs in the ash from sludge from Gävle up to 1992, i.e. 6 years after the Chernobyl accident, would have been over 5 kBq/kg.

3.12 Incinerating refuse

Refuse contains varying levels of naturally occurring radioactive substances and ^{137}Cs, etc from the surroundings. Household and industrial refuse may also contain radioactive products that are either permitted to be thrown away as refuse (an occasional smoke detector containing ^{241}Am, the wick from a propane lamp, etc) or other refuse that is thrown away by mistake or through ignorance.

3.13 Burning biofuels and peat

Biofuel is defined as fuel composed of biomass, i.e. material of biological origins that has not been chemically transformed or has been transformed to a very limited extent (SOU, 1992). Biofuels include wood fuels, straw, reeds, etc. According to this definition, peat is not considered a biofuel. However, peat and the various biofuels are used, often at the same time, in heating plants, making it logical to deal with them in the same chapter.

Wood fuels (chips)

"Wood fuels" is the term used for fuel extracted from wood and may also include branches and twigs that are left behind from felling activities. Energy forests and recycled wood (lumber from demolished buildings) can also be grouped under this heading. When wood from an energy forest has been harvested, it is shredded into chips that are then used as fuel. While chips from the above mentioned materials contain high levels of 137Cs, energy forests contain low or very low levels of ^{137}Cs, depending on location.

The use of wood fuels, and chips in particular, for the production of energy for local heating or heat and power plants is a growing source of energy in Sweden that amounted to 12 TWh in 1996 (Association of Heating Plants, 1996). This was approximately 20% of the fuel volume consumed. Production and

the use of sulphate and sulphite lyes in the pulp and paper industry amounted to 31 TWh in 1996 (table 3.8). In the pulp and paper and forest industries, a total of 16 TWh of wood fuels were used in 1996. The total energy production from burning wood chips was 67 TWh in 1996 (table 3.8). In the statistics available, some of the material reported under the heading by-products in the pulp and paper and forest industries may also have been reported under the heading of wood fuel – heating plants.

Table 3.8: Energy produced in Sweden by burning various biofuels and peat.

Energy source	**Energy production (TWh)**			
	1993	**1994**	**1995**	**1996**
Lyes, pulp and paper industry	30	30	31	31
By-products, pulp and paper industry	9	8	8	7
Biofuels for el. production	2	2	2	2
By-products, saw mills	7	8	8	9
Wood fuel, heating plants	8	9	10	12
Pine oil, heating plants	1	1	1	2
Waste, heating plants	4	4	5	5
Peat, industry & heating plants	4	3	4	4
Subtotal	65	65	69	72
Wood fuel, single-family houses	12	11	11	12
Total	77	76	80	84

The naturally occurring radionuclides ^{40}K, ^{235}U, ^{238}U and ^{232}Th are evenly spread from the surface of the ground and down to a depth that applies to different types of trees. The majority of the substances from the radioactive fallout caused by the

superpowers' nuclear weapons testing in the atmosphere and the Chernobyl accident were found to have accumulated in the upper soil levels, down to a depth of 30 cm (numerous studies in Sweden Norway and the rest of Europe). Of the radionuclides that were detected shortly after the accident, ^{54}Mn, ^{60}Co, ^{99}Tc, ^{103}Ru, ^{106}Ru, ^{110m}Ag, ^{125}Sb, ^{134}Cs, ^{137}Cs and ^{144}Ce, only ^{137}Cs, due to its long half-life (T½=30.15 years) remains in slightly traceable amounts. After the reactor accident at Chernobyl, a total of 4 PBq ^{137}Cs was deposited very unevenly across Sweden.

Table 3.9 summarises the concentrations of radioactivity, measured in Bq/kg (dry weight), for a number of radionuclides that occur in peat and wood chips as well as the concentrations in fly ash (from Hedvall, 1997). The figures are those that can be expected today (1998). Immediately after the Chernobyl accident, large concentrations of radioactivity in the form of short-lived radionuclides, e.g. up to 2000 Bq/kg ^{103}Ru and ^{106}Ru could be measured in fly ash from peat.

Table 3.9: Concentrations of radioactivity, measured in Bq/kg (dry weight) for a number of different radionuclides occurring in peat and wood chips, and the concentration in fly ash (from Hedvall, 1997).

	Peat (Bq/kg)		**Wood chips (Bq/kg)**	
Radionuclide	**Fuel**	**fly ash**	**fuel**	**fly ash**
Be-7	50-250	1800-5600	-	-
K-40	10-40	<1500	40-800	170-2200
Sr-90	-	-	5-7	800-2700
Cs-134	2-150	<260	<5	<30
Cs-137	30-165	40-34500	1-500	40-4500
Pb-210	30-200	140-1300	<70	<3200
Ra-226	10-20	<215	<2	60-200
Ac-228	5-15	60-135	<2	30-80
Th-230	-	100-200	-	-
Th-234	5-35	380-1000	-	--
Pa-234	70-90	220-1300	-	--
U-234-238	5-125	275-1400	0.05-0.20	1.5-8
U-235	0.2-7	25-65	0.01-0.04	-
U-238	16-90	270-1050	-	-

How have the concentrations of radioactivity changed in wood fuels since 1986? Nylén and Ericsson (1989) showed that the concentration of ^{137}Cs decreased from 10 kBq/kg to 4 kBq/kg in pine needles between 1986 and 87. This was mainly due to an increase in the biomass. A rapid decrease in concentrations of radioactivity in the needles during the summer of 1986 can be explained by the fact that it was washed away by rain. A more extensive series of measurements on the concentration of ^{137}Cs in spruce needles from northern Skåne has shown only a 50% reduction in concentration between 1987 and 1997. If the physical half-life is taken into consideration, the biological reduction is only 25-30% during the ten-year period (Mattsson and Erlandssson, 1998). If these observations are juxtaposed to forested areas in central Sweden that were subjected to considerably more fallout than Skåne, this should be mirrored in measurements from the heating plant in Enköping where samples were collected from 1987 to 1997 (table 3.10). The measurements, which encompassed both wood chips and fly ash samples, showed very great variations. This can be explained by the very great variations in deposits of ^{137}Cs within the area from which wood for chips is gathered for the heating plant. It has proven to be very difficult to use the geographical location of the energy producer as a means of drawing any conclusions regarding the expected values for concentrations of radioactivity in wood chip fuel and also in the resulting ash products.

Table 3.10: Concentrations of radioactivity (Bq/kg) of ^{137}Cs and 40K in wood chips, fly ash and bottom ash collected in the form of annual random samples taken at Enköping's heating plant (Erlandsson, 1998). The material also contains a number of other radionuclides, primarily natural ones.

	^{137}Cs concentration (Bq/kg)			
Year	**Radionuclide**	**Wood chips**	**Fly ash**	**Bottom ash**
1986/87	^{40}K	44	1200	---
	^{137}Cs	550	17900	---
1988/89	^{40}K	83	1470	---
	^{137}Cs	320	5000	---
1989/90	^{40}K	66	3600	---
	137Cs	73	3300	---
1990/91	^{40}K	64	1780	---
	^{137}Cs	180	5600	---
1993/94	^{40}K	---	2680	---
	^{137}Cs	380	8700	---
1994/95	^{40}K	39	5240	1330
	^{137}Cs	150	16300	2600
1996/97	^{40}K	---	---	---
	^{137}Cs	---	9500	900

Peat

Peat is an organic soil type that has been formed during the last 10,000 years due to the fact that plants have not mouldered completely because of a lack of oxygen. Peat that is used as fuel is sometimes considered a biofuel but is sometimes classified as a fossil fuel. In 1996, energy production in Sweden by burning peat primarily in district heating plants amounted to 4 TWh (NUTEK, 1996). Peat accounts for a very small share (6%) of the energy produced through combustion.

After the Chernobyl accident, a number of short-lived radionuclides, such as ^{54}Mn, ^{60}Co, ^{98}Tc, ^{103}Ru, ^{106}Ru, ^{110m}Ag and ^{144}Ce, were measured in peat. Today, only ^{137}Cs and to a limited extent ^{134}Cs occur in measurable concentrations. Naturally occurring radioactive substances in the uranium and thorium series also occur in peat. Peat from certain areas can have such high concentrations of radioactive substances that its use as fuel is not recommended considering the fact that further enrichment occurs when the it is burned and converted into ash products.

The products in the radioactive decay chain in peat are not in radioactive equilibrium due to the elements' varying solubility in water and their varying capacity to be adsorbed by the peat. The levels of radionuclides in the moss can vary greatly, both laterally and in depth. These variations have been particularly reported for uranium levels.

Large amounts of fission products were deposited as a result of the superpowers' nuclear tests in the atmosphere in the early 1960's. ^{137}Cs levels in Finnish combustible peat before Chernobyl, measured by Mustonen and Sinkko (1981), were approximately 50 Bq/kg, see table 3.11.

Table 3.11: Concentrations of radioactivity in dry peat before Chernobyl – average values for 66 samples (Mustonen and Sinkko, 1981)

	Concentrations of radioactivity (Bq/kg)							
	^{238}U	^{226}Ra	^{228}Ra	^{228}Th	^{235}U	^{40}K	^{137}Cs	^{210}Pb
Peat	-	6.4	2.5	2.1	-	23	46	84
Bottom ash	30	30	14	14	1.5	360	170	85
Fly ash	160	117	46	44	8.2	385	810	970

The reactor accident at Chernobyl lead to a great increase in the deposit of ^{137}Cs in the country, which was very unevenly distributed. As has already been mentioned, a total of approximately 4 PBq of ^{137}Ca was deposited. An inventory of peat moss, carried out by The Swedish Radiation Protection Institute (SSI) in 6 counties affected by fallout, showed ^{137}Cs levels in samples of peat ash to be between 1 and slightly over 40 kBq/kg. The average was 10 kBq/kg, corresponding to approximately 500 Bq/kg in dry peat.

Straw and other energy crops

There is very little information on the importance of burning straw for heating or on the radionuclide content of straw ash. During 1991, less than 0.5 TWh was produced by burning straw but the potential is estimated to be 11TWh (SOU, 1992). In addition to straw, reeds, grass and other energy crops can be used. Their potential is estimated at 2 TWh/year. Since energy production is on such a small scale, we have elected not to continue analysing concentrations of radioactivity and radiation doses. If growing crops are exposed to fallout, special attention must be paid to concentrations of radioactivity in the fuel and ash. If the crops or grass grow after fallout has occurred, levels will be low since very little radioactivity is absorbed through the roots.

Radioactive releases from burning wood chips and peat

Very little production information from heating plants in Sweden is available. Using data collected from 13 heating plants located all over Sweden, Hedvall et al. (1966) calculated that burning wood chips to produce 1 MWh results in between 6 and 9 kg of ash and 12-13 kg ash if dry peat is burned. The uncertainty resulting from the quality of the fuel and the condition of the plant is estimated to be 25%.

The total generated thermal energy, total activity of ^{137}Cs, the average concentration of radioactivity and the total amount of ash from peat and wood chips for approximately 150 heat-producing members of the Heating Plants Association have been calculated for the different heating plants (table 3.12). The table shows that during the production season 1990/1991, 111 GBq ^{137}Cs was redistributed between fuel and ash.

Table 3.12: The total generated thermal energy, total activity of 137Cs, the average concentrations of radioactivity per kg ash for peat and wood chips for approximately 150 heat producing members of the Heating Plants Association. The table also includes the calculated amount of ash.

	1986/87	1988/89	1989/90	1990/91
Peat				
Thermal energy (GWh)	1585	1949	2642	3021
Total ^{137}Cs activity (GBq)	101	81	94	75
ACR* (kBq/kg)	5.3	3.5	3.0	2.1
Total ash (10^6 kg)	19.0	23.4	31.7	36.3
Wood chips				
Thermal energy (GWh)	3333	3085	3465	4419
Total ^{137}Cs activity (GBq)	58	36	32	36
ACR*. (kBq/kg)	2.2	1.5	1.2	1.0
Total ash (10^6 kg)	26.7	24.7	27.7	35.4

* Average concentration of radioactivity

In a statement from SSI (dated February 27, 1997) on a license application for a wood chip (peat)-fired heating plant in the municipality of Gävle it was stated that

> "Until such time as a decision has been made as to how ash containing ^{137}Cs should be handled, ash containing levels above 5 kBq/kg should be deposited in special landfills. Ash with levels of ^{137}Cs lower than 5 kBq/kg should, without restriction, be: 1) deposited in private or municipal landfills or 2) returned to the forest as a soil improvement agents. Before the re-fertilisation of forest in the same area with caesium contaminated ash, consideration should be given to local conditions."

With this statement in mind, it is of interest to attempt to form an opinion on the way in which the supply of fuel in a wood chip (and peat)-fired heating plant is accomplished and its impact on the ^{137}Cs content in the ash. A correlation between the deposit of ^{137}Cs in the area and the concentrations of radioactivity in the fuel has been established by Hedvall et al. (1997) (figure 3.1). One problem in this respect is the fact that the fuel is sometimes transported long distances and therefore does not necessarily mirror local conditions. However, if we consider the heating plant in Enköping for which we have the best information on the wood chip fuel used, and take an average concentration of radioactivity for the period 1994-1997 of 11,500 Bq/kg in the fly ash (table 3.10) and an enrichment factor between the fuel and the fly ash of 43, this leads to an average radioactivity of 270 Bq/kg in the fuel. This value was supported by the measurements from random samples (table 3.10). Fuel for the heating plant in Enköping has been taken from an area to the north of the town where deposits, according to SGAB's map (1986), were between 20 and 40 kBq/m^2 (figure 3.1). A concentration of radioactivity of ^{137}Cs of 5 kBq/kg in the fly ash with an enrichment factor of 43, is the equivalent of a concentration of 115 Bq/kg, which is obtained for a deposit of between 12 and 17 kBq/m^2. This value is valid for today's conditions and is the equivalent of an original deposit of between 15 and 25 kBq/m^2. This means that forest products for use as combustible fuels cannot be taken from areas with higher deposits

according to SGAB's map without producing fly ash that would exceed SSI's established limit. This zone is marked on SGAB's map in figure 3.2. If exceptions were only made for areas with deposits of 100 kBq/m^2or higher, a limit of 50 kBq/m2 would be "needed". This is a new situation for energy producers (the Heating Plants Association, pulp and paper and forest industries). Considering the transport situation of today, the fuel could have its origins far from the area where the energy is produced. Therefore, the producers must continually check the levels of ^{137}Cs in both the fuel and the ash.

Handling contaminated peat during harvesting, burning and ash deposits can lead to both external and internal radiation doses. Wijk and Jensen (1990) suggest the concentrations of radioactivity from the following radionuclides, ^{235,238}U, ^{232}Th, ^{226}Ra, ^{210}Pb, ^{210} Po and ^{137}Cs should be taken into consideration when granting a license to harvest peat in a given area. Since the Chernobyl accident, the concentrations in Sweden at which steps are taken to lower the radiation levels for ^{137}Cs are 5 kBq/kg for use as combustible fuel, 1 kBq/kg for peat with 50% dry weight if the peat is to be used for growing vegetables and 3 kBq/kg for use as lawn fertiliser.

The combustion process always entails the enrichment of radioactive substances in sludge and ash since carbon leaves the fuel in the form of carbon dioxide. The same amount of radioactive substances also occur somewhere in the waste products (sludge, ash and flue gases). Since the volume of waste products is less than the volume of the fuel, the concentrations of radioactive substances increase from the fuel to the waste products. The ash content in burned peat is approximately 5%.

Radioactivity in fuel (Bq/kg)

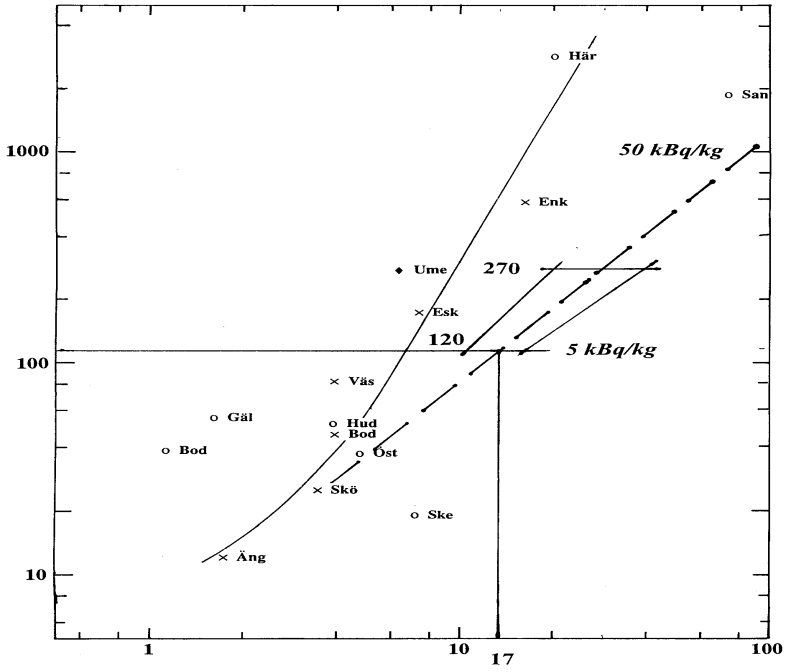

Figure 3.1: The figure shows the empirical correlation between the deposit of ^{137}Cs (kBq/m^2) and concentrations of radioactivity of ^{137}Cs (Bq/kg dry weight) in different types of fuel. The figure is taken from Hedvall *et al*., (1996).

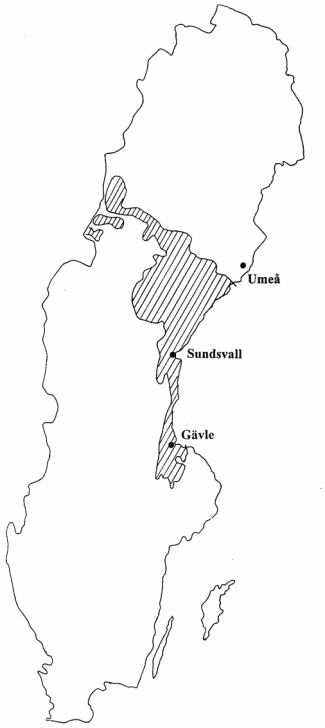

Figure 3.2: The shaded section indicates the area where fallout from the Chernobyl accident was higher than 20 kBq/m2. Figure 3.1 shows a concentration of radioactivity of 120 Bq/kg in wood chip fuel, the equivalent of 5 kBq/kg in fly ash.

Returning ash after burning biofuels

As is the case with burning peat and coal, burning biofuels also produces large amounts of ash that must be disposed of. There are well-documented rules for disposing of coal and peat ash but these rules pertain primarily to non-radioactive substances. In regard to ash from biofuels, there is great interest in returning the nutritive

substances to the land where the biofuels were grown. If this is not done, the soil will eventually be depleted of nutritive substances. One radionuclide, ^{137}Cs, presents the primary radiation problem today. The extent of this problem will depend on the amount of ash that is spread per unit of soil, as well as the potassium content of the ash (the higher the potassium content, the lower the amount of caesium that is absorbed by vegetation).

3.14 The need to limit radioactive releases and waste

Radioactive releases from combustion facilities can lead to a radiation dose contribution to people through inhalation, deposits on the ground and via radiation leakage from landfills where waste has been deposited.

Regarding radiation doses to people in the vicinity ("critical group"), Mustonen (1989) calculated that the releases from a 1,000 MW peat-fired heating plant gives an effective dose (through inhalation) of 0.001 mSv per year (before the Chernobyl accident). Hedvall and Erlandsson (1992) calculated the dose to a critical group near a peat-fired heating plant in Sandviken to be 6 µSv/year or 0.2 mSv/GWyr. Hedvall et al. (1996) calculated the effective dose from inhalation to be 2 µSv/year, the equivalent of 0.35 mSv/GWyr. Consequently, the radiation dose through breathing to people living in the vicinity is very low. This also pertains to external radiation from material deposited on the ground. The deposit of combustion waste considered hazardous to the environment is regulated through licensing under the Environmental Protection Act. Matters concerning ionising radiation and radioactive substances are not covered by this legislation. In 1986, SSI issued instructions regarding the handling and depositing of ash produced by burning peat. There is a formal requirement for a license according to the Act on Nuclear Activities for handling material containing more than 200 µg/g of natural or depleted uranium or thorium. Special rules, issued by

the Swedish Rescue Services Agency (SRV), apply to transporting material containing more that 70kBq/kg.

Measurements taken 1 meter from a container of fly ash with a ^{137}Cs concentration of 12-22 kBq/kg registered a maximum dose rate of 0.005 mSv/h. Personal dosimeters, with a lowest detection level of 0.01 mSv, did not show a measurable level of radiation during a 4-week period.

In the worst case (all radioactivity in a thin outer layer), a ^{137}CS deposit of 1 kBq/m^2 yields approximately 2 nGy per hour, i.e. approximately 50 nGy/day or 0.02 mGy/year. If a contribution of 0.1 mSv/year from burning biofuels is permitted, 6.0 kBq/m^2 could be deposited. If 0.1 kg/m^2 is deposited, a concentration of 60 kBq/kg in the ash would be acceptable. The thickness of the layer of waste in landfills is considerable, in some cases perhaps as much as several meters. The dose rate one meter above a very thick layer of ^{137}Cs with a concentration of 1 kBq/m^3 is 0.2 nSv/hour. The probable reading above an actual layer of waste could be 0.1-1 µSv/hour (Ravila and Holm, 1996).

After the Chernobyl accident, SSI issued instructions for handling and depositing peat ash with high levels of $^{137,134}Cs$. Before a load of ash can be deposited in a normal tip or in a landfill specially designed for peat ash, samples should be taken from the ash to be deposited. The samples are combined in a monthly sample. The amount of ash, the average monthly figure for ^{137}Cs and the name of the tip are all noted in a quarterly report to SSI, which should be contacted if the average monthly figure exceeds 50 kBq/kg.

Since wood chips have a lower content of naturally occurring radioactive substances from the uranium and thorium series and lower levels of ^{137}Cs, a higher wood chip content reduces both the releases and the concentrations of radioactivity in the ash.

3.15 Comparison of radioactive releases and radiation doses from different types of energy producing plants

As has been previously mentioned, Sweden's supply of energy is based primarily on oil (40%), hydropower, nuclear energy and biofuels (17-19% each), coal (4%) and gas (2%). The problem of radioactive releases, radiation doses and waste from the nuclear power industry are well known and frequently discussed. Radiological problems from the petroleum industry have received less attention in Sweden, primarily because we have no domestic extraction of oil. As large-scale consumers of oil however, we must consider the problems that arise through the entire chain - from extracting the oil to its combustion. Radiation doses from deposits in pipes of naturally occurring radioactive substances, which can be found in bedrock and sea water, can be substantial and cleaning these types of pipes can produce low and intermediate level waste which must occasionally be stored on land. Radiological problems from hydropower are associated with radon in underground areas. As with other work performed indoors or underground, this problem must be alleviated through improved ventilation. If this is neglected, personnel can be subjected to substantial doses of radiation. Under normal circumstances, burning biofuels produces a lesser amount of naturally occurring radioactive substances. The fallout from the Chernobyl accident has lead to such high levels of ^{137}Cs in the biofuel from certain areas that the ash must be handled in specially prepared landfills. Similar types of landfills are already in use for coal ash. This is primarily justified by the content of toxic heavy metals, etc and not by the radioactive substances. It is vital that the radioactive content in releases and waste from energy-producing facilities other than nuclear power plants be judged in the same way or according to the same rules as those governing nuclear releases and waste.

Even in an area of limited scope, such as radiation, it is difficult to compare the effects of different types of energy

production fairly. The first difficulty is that aside from nuclear power, other methods for producing energy are generally not associated with radiation or radioactive waste at all. It is particularly difficult to assess the consequences of the releases of radionuclides with a long half-life and whose dose contributions are not noticeable until long afterwards. Another difficulty is the fact that different types of energy production release different radioactive substances. It is true that per unit of energy produced, wood chip and peat-fired heating plants can release more ^{137}Cs into the air than a nuclear power plant. This was the case even before the Chernobyl accident, as a result of the fallout from nuclear weapons testing in the atmosphere. On the other hand, the nuclear power industry releases radionuclides that do not occur in biofuels and the level of radioactivity in nuclear waste is much higher. The total radiological impact per unit of energy produced from the nuclear power industry, to both the public and to its own employees, is greater than e.g. from burning wood chips. The total radiological impact from burning peat is considered to be greater than from burning wood chips but less than from burning coal.

Table 3.13: Contribution to the public's collective dose from Swedish energy production. The contribution from naturally occurring background radiation is given for comparison.

Source	**Nuclear energy**	**Coal**	**Oil**	**Wood chips**	**Peat**	**Natural radiation**
Annual energy production (GWyr)	7.4	3.2	9.7	8.6	0.5	
Collective dose per unit produced energy (manSv/GWyr) (acc. UNSCEAR, 1993)	Local and reg.: 1.3 Global: (^{14}C): 17 Total: 200	20	0.5	1	2	
Annual collective dose-contribution (manSv)	Local and reg.: 10 Global: 130 Total 1500 (acc. UNSCEAR)	64	5	9	1	9000*

*) excluding the contribution from radon and daughters of radon

References

Christensen, T., Fuglestvedt, A. and Benestad, Ch. (1994). Kemiske riskfaktorer ved enkelte industrielle processer (energi-produksjon). Bilagsrapport 6 till RAS-430 Nordiska Kontak-organet för Atomenergi (NKA).

Eisenbud, M. and Petrow, H. G. (1964). Radioactivity in the atmospheric effluents of power plants that use fossil fuels. *Science*, **144**, 288-9.

Energy Report Series (1985). The environmental impacts of production and use of energy sources. Part IV - the comparative assessment of the environmental impacts of energy sources. ERS-14-85, Nairobi, January 1985.

Erlandsson, B. (1998). Aktivitetskoncentrationen av Cs-137 i flis, flygaska och bottenaska i årliga stickprov från Enköpings värmeverk. Personal communication.

Gesell, T. F. (1975). Occupational radiation exposure due to Rn-222 in natural gas and natural gas products. *Health Phys*., **29**, 681-7.

Hedvall, R. and Erlandsson, B. (1992). Radioactivity in peat fuel and ash from a peat-fired power plant. *J. Environ. Radioactivity*, **16**, 205-228.

Hedvall, R., Erlandsson, B. and Mattsson, S. (1996). Cs-137 in fuels and ash products from biofuel power plants in Sweden. *J. Environ. Radioactivity*, **31**, 103-17.

Hedvall, R. (1997). Activity concentration of radionuclides in energy production from peat, wood chips and straw. Thesis, Lund 1997.

Inskip, P. D., Wang, Z. and Fen, Y. (1991). Suitability of Chinese oil well loggers for an epidemiological study of the carcinogenic effects of neutrons. *Health Phys*., **61**, 637-40

Kristensen, D. (1994). Radioactive avleiringer i oljeproduktion - en strålehygienisk utreding, Strålevern Rapport 1994:7, Statens strålevern, Österås, Norway.

Livsmedelsverket, (1998). Har du radon i ditt dricksvatten? Livsmedelsverket, Stockholm

Martin, A., Mead, S. and Wade, B. O. (1997). Materials containing natural radionuclides in enhanced concentrations. Report EUR 17625. Luxembourg: Office for Official Publications of the European Communities ISBN 92-828-0191-8.

Mattsson, S. and Erlandsson, B (1998). Personal communication.

McLennan, J. C. (1904). On the radio-activity of natural gas. *Nature*, **70**, 103-08.

Mustonen, R. (1989). Naturlig strålning i samband med energiproduktion i Norden. Bilagsrapport 4 till projekt RAS-430.

Mustonen, R. and Sinkko, (1981). Radioactivity of peat, coal and their combustion products. Report STL-B-36, STUK, Helsingfors, Finland (In Finnish).

Mustonen, R., and Jantunen, M. J. (1985). Radioactivity of size fractionated fly ash emissions from a peat- and oil-fired power plant. *Health Physics*, **49**, 1251-60.

NCRP 95 (1987). Radiation exposure of the U.S. population from consumer products and miscellaneous sources. National Council on Radiation protection and Measurements , Washington, D.C., USA

NKA (1989). Nordic liaison committee for atomic energy (1989). Project RAS-430. National Institute of Radiation Hygiene, Norway.

NUTEK. (1996). Energiläget i Sverige 1996, Stockholm 1996.

Nylén, T. and Ericsson, A. (1989). Uptake and retention of Cs-137 in scots pine. Regional congress of the International Radiation Protection Association (IRPA) on the radioecology of natural and artificial radionuclides. Visby, Sweden, 10-14 September 1989.

Okamoto, K. (1980). Contamination of seafood by radioactivity produced from burning of coal and other fossil fuels. *Radiat. Eff. Aqat. Org*., 45-58.

Ravila, A. and Holm, E. (1994). Radioactive elements in forest industry. *Sci. Total Envron*., **157**, 339-356

Rogers, V. C. (1991). Disposal alternatives for oil and gas NORM. Abstract, 36th Annual Meeting of the Health Physics Society. Health Phys., 60,

SCB (1994-1996) Statistiska centralbyråns årsböcker 1993-1995.

SGAB (1986). Map of Sweden showing the fallout levels of Cs-137 after the Chernobyl accident. Swedish Geological Company, Box 1424. S-751 44, Uppsala, Sweden.

SSI (1991-1997). Statens strålskyddsinstitut. Kärnkraftindustrins - aktivitetsutsläpp - yrkesexponeringen 1989-1996. SSI-rapporterna 91-05, 91-11, 92-15, 93-23, 94-05, 95-13, 96-15 and 97-19.

SSI (1998). Remissyttrande över ansökan om tillstånd till miljöfarlig verksamhet, Gävle Kraftvärme AB, Gävle

SOU (1992). Biofuels in the future. Allmänna Förlaget, SOU 1992:90 SSSN 0375-250X.

UNSCEAR (1988). Sources, effects and risks of ionising radiation. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR Report to the General Assembly, New York.

UNSCEAR (1993). Sources and effects of ionizing radiation. United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR Report to the General Assembly, New York.

USAEC (1973). Comparative risk-cost-benefit study of alternative energy. Wash-1224-A, US Atomic Energy Commission, Washington, DC.

Whitehead, N.E. (1980). Radon measurements at three New Zealand geothermal areas. *Geothermics*, **9**, 279-86.

Glossary

Absorbed dose: "Radiation dose" – the amount of energy per unit of weight that is absorbed by a body exposed to radiation. The unit used in 1 gray (Gy); 1Gy=1 joule/kg.

Activity: The amount of decay per unit of time in a radioactive substance; expressed in the unit becquerel (Bq); 1 Bq = 1 decay/second.

Dose: Used in this chapter to mean normal effective dose (see below).

Dose rate: Radiation dose per unit of time.

Effective dose: "Radiation dose". To compare radiation doses from different radiation situations, the whole-body exposure is normally calculated which can be expected to pose the same risks for severe damage as the irradiation of one part of the body. The varying radiation sensitivity of various organs and tissues must be taken into account.

ICRP: International Commission on Radiological Protection.

Isotope: Atoms with the same atomic number and number of protons, but with a different number of neutrons.

Ionising radiation: Radiation that has sufficient energy to detach electrons from atoms and molecules, i.e. sufficient to produce ions.

Collective dose: If the present and future doses of radiation caused by one year's work are summarised for all individuals in the immediate vicinity, locally and globally, this produces the collective dose. That is, the total radiation effect caused by one year's activities (e.g. SSI's reference value: 5 manSv per year and GW electricity (installed effect). The unit used is man sievert (manSv)).

Critical group: A group of people living near a facility that releases radioactive substances into the surroundings. This is a group that, because of living habits, age or place of residence, is assumed to receive the highest additional dose of radiation from the releases.

Naturally occurring radiation (background radiation): Radiation from sources that are a natural part of the environment. This includes cosmic radiation, radiation from naturally radioactive potassium (40K) in the body and external radiation from the soil and buildings. Altogether, these natural sources of radiation provide people in Sweden with a radiation dose of approximately 1 mSv per year. This value is the background used in this chapter to calculate the additional dose received from different energy producing facilities. The dose of radiation to the lungs and air passages from daughters of radon in indoor air in Sweden is considered on average to be the approximate equivalent of full body irradiation of an additional 2 mSv/year. Since this estimate contains significant uncertainties and since this contribution can vary greatly from place to place, it is not suitable to include this contribution in the figure used for comparison.

Radioactivity: The property of a substance to release ionising radiation.

Radioactive substance: a substance that contains atoms with unstable nuclei that become stable through decay. Ionising radiation is released as the substance decays.

Radiation: The transport of energy in the form of waves or particles.

4 Transporting spent nuclear fuel to a deep repository

4.1 Background

When planning the final disposal of spent fuel from the Swedish nuclear power-producing reactors, the Swedish Nuclear Fuel and Waste Management Co (SKB) follows a course of action calling for the spent fuel to eventually be encapsulated in a thick and robust metal canister, after which it will be placed in a deep repository in stable bedrock in Sweden. A number of feasibility studies are underway in an effort to find a suitable site for the repository. If the repository is located near the coast, transport can be carried out primarily by sea, i.e. the ship Sigyn or its successor, which will transport the spent fuel from the Central Interim Storage Facility for Spent Nuclear Fuel (CLAB), near the Oskarshamn nuclear power plant. If the repository is located in an inland municipality, transport will be carried out by road and/or by rail.

The following report will provide a general overview of how and to what extent transport may be carried out between CLAB and the deep repository, as well as a summary of the regulations pertaining to the transport of spent nuclear fuel and other long-lived waste. In addition, the requirements for the transport containers and the tests performed to verify that the requirements have been fulfilled will be discussed, followed by a review of experience gained in this area from Sweden and other countries. Examples will also be given of relevant risk and consequence analyses, followed by a summary of the current scope of knowledge.

The facts in this chapter have been taken from the regulations governing international transport of radioactive material, from international conferences in this field, from SKB's planning and experience as well as from other investigations and experience gained in Sweden.

During the two most recent international conferences on the transport of radioactive material (PATRAM '92 and PATRAM '95), the experiences and results from a number of countries were reported. Some of this material will be referred to in this chapter. The next conference will be held in mid-1998. Documentation has also been used from a meeting of the panel held in the USA in November 1997 on the initiative of the Nuclear Waste Technical Review Board (NWTRB 1997), the American counterpart of the Swedish National Council for Nuclear Waste (KASAM). On this occasion, the government agencies and research laboratories involved, with many years of experience in this area, reported on their studies, results and assessments. The theme was safety issues in connection with the transport of spent nuclear fuel. The meeting of the panel was held against a background of, and in preparation for, the fact that the United States, as in Sweden, would deposit non-reprocessed, spent fuel from nuclear power plants directly in a repository.

4.2 How will transport be carried out and to what extent?

Encapsulated spent nuclear fuel is transported from an encapsulation facility, that SKB expects to build near CLAB, by ship to a coastal harbour and then, if necessary, by road or rail to the deep repository. Theoretically, the encapsulation facility could be built at the site of the repository or elsewhere, but a facility near CLAB should be considered the primary alternative in SKB's planning.

If the deep repository is located near the coast, sea transport supplemented by vehicles at the harbour terminal could be sufficient. SKB estimates that approximately 200 containers of

encapsulated fuel would be transported annually during the deposition period. In addition, transport of other types of waste, bentonite clay, sand, etc would also be carried out. The deposition phase is estimated to go on for approximately 30 years. SKB has carried out studies showing how transport could be arranged to either an inland site (SKB 1995) or to a coastal community (SKB 1996). It is planned that the transport will begin in the year 2010 at the earliest, with full-scale operations lasting for 20 years, between 2020 and 2040.

4.3 Regulations governing the transport of spent nuclear fuel

In terms of safety, the transport of hazardous materials, including radioactive substances, is controlled by a number of different international regulations, which also apply in Sweden. There are regulations for all types of transport, i.e. by road, rail, sea or by air. The regulations that apply specifically to radioactive substances are based on international recommendations issued by the United Nation's International Atomic Energy Agency IAEA (IAEA 1990 and 1996).

The regulations for packaging, marking and shielding against radiation are adapted to the radiological characteristics of the contents. Small sources of radiation for, e.g. industrial or medical use do not require the same approved packaging as spent nuclear fuel. If the level of radioactivity exceeds a certain level, a B-container must be used. This level is 1 TBq (1 TBq=10^{12}Bq) for caesium-137.

Spent fuel emits a great deal of radiation that must be reduced by shielding in order for the fuel to be handled, stored and transported. This is done at CLAB by storing the fuel in water that is several meters deeper than the length of the rods. B-containers are always used when transporting spent nuclear fuel. These are cylindrical containers made of 30 cm thick steel that shield against the powerful radiation sufficiently and effectively encapsulate the

radioactive material. They are designed so that criticality, i.e. a sustained chain reaction, can essentially be eliminated. B-containers, fitted with cooling flanges, are used when spent nuclear fuel is transported from a nuclear power plant. These cooling flanges reduce heat generation and moderate the temperature. No cooling flanges are needed when, after approximately 30 year's storage at CLAB, the fuel is transported to the deep repository. At this point, the levels of radioactivity and heat have decreased by 90% and correspondingly are at a level that is only 10% of what it was one year after the fuel was removed from the reactor.

Transport of spent nuclear fuel is encompassed by the Swedish Nuclear Power Inspectorate's (SKI) regulations for the physical protection of fissile material, which are intended to ensure that none of this material is lost?misplaced. Special routines for monitoring, delivering, communications and reporting are utilised to achieve this physical protection.

4.4 Transporting type B-containers

Type B-containers are designed to reduce the radiation and encapsulate the spent nuclear fuel and to withstand demanding conditions, including serious transport accidents such as fires or collisions, without jeopardising the necessary shielding and encapsulation functions. Figure 4.1 shows a cross-section of a B-container used to transport spent fuel to the deep repository. The canister containing the spent fuel is the container that will be deposited in the repository. During transport, it is enclosed in a transport container – a steel cylinder that will have a 20-30 cm thick casing. Shock absorbers are placed at both ends of the transport container to reduce the forces in the event of a collision. The transport vehicle is equipped with load carriers that hold the container in place. The spent fuel, in 4 meter long encapsulation tubes, is placed inside the canister, which may consist of an outer casing of 5 cm thick copper with a forged steel insert containing channels for the fuel rods. The entire package contains a number of barriers to contain the radioactivity: the uranium dioxide ceramic, the fuel cladding, the double-layered disposal canister (see also

figure 5.2) and finally, the transport container. The canister containing the waste and the transport container combined are estimated to weigh approximately 55 metric tonnes.

The radiation shielding is to be designed so that the dose rate (i.e. the dose of radiation per unit of time) will not exceed 2 mSv per hour on the outer surface of the container (1 mSv= one milliSievert= 1/1000 Sievert). Furthermore, the dose rate must be less than 0.1 mSv per hour at a distance of one meter from the package. These requirements have been established so that no one is exposed to an extra dose of radiation that is higher than 1 mSv per year [1].

The radiation from transporting spent nuclear fuel does not expose the public to a significant extra dose of radiation, even if someone were to stand next to the transport vehicle for several hours. This can be illustrated by another example. Anyone living or standing 10 meters from a road, where, say, 100 vehicles transporting spent fuel pass each year and stop for two minutes at a traffic light, could receive a maximum dose of radiation of 0.004 mSv per year, which is less than one percent of the naturally occurring background radiation.

As previously mentioned, B-containers are designed to withstand severe accidents. Design specifications require that the container must be able to withstand a 9 meter fall onto a rigid surface, a 1 meter fall against a metal rod that strikes the weakest point on the container, a fire for 30 minutes at 800° C, or immersion in water to a depth of 200 meters. After having gone through this entire event sequence, the shielding characteristics must not have deteriorated to more than 10 mSv per hour at 1 meter's distance and leakage must not have increased by more than certain values specified by the IAEA.

Among other fissile materials and actinides, a B-container holding 2 tonnes of spent fuel that is being transported from CLAB

[1] This can be compared with the applicable dose limits. The maximum limit for people performing radiological work is 50 mSv for a single year and a total of 100 mSv during a period of five consecutive years. The limit for other personnel is the same as for the public – 1 mSv/year.

to the deep repository may contain 7,000 TBq caesium-137. Not more than 1 TBq caesium-137, i.e. 0.01% in this case, may leak out during a one week period after the sequence accident mentioned above. The radiation dose from a leakage 10 times this amount will be discussed in the section on risk and consequence analyses.

4.5 Testing B-containers

To ensure that the transport containers can withstand the adverse conditions for which they are designed, they are subjected to realistic type tests that simulate the accident sequence mentioned above as closely as possible. The manner in which these tests should be carried out has been prescribed in instructions from IAEA. After testing, the amount of leakage that may have occurred is determined, which can be done by applying pressure and measuring pressure equalisation.

It is unlikely, but not impossible, that accident conditions could be even more severe than those that the internationally established testing standards are intended to cover. Studies have been made in the United States showing that only 1% of all transport accidents included in the study took place under circumstances that were more severe than those specified for B-container testing (NWTRB 1997). Careful analyses and tests have been made of accidents beyond the design basis, whose consequences and results will be discussed later in the section on risk and consequence analyses.

It is conceivable that the container could fall from a height of more than 9 meters. In this case, would the container burst? The answer lies in the fact that the design criteria contain ample margins of safety. To begin with, the design criteria call for a container that can withstand a 9-meter fall onto a rigid surface. For the designers, this means that the container must be able to absorb all of the kinetic energy generated by the fall. For testing purposes, the rigid surface is simulated by a thick steel plate placed on a reinforced concrete foundation. In reality, there are no totally rigid surfaces. A fall of 20 meters onto a slab? of concrete is the approximate equivalent of a 9 meter fall onto a rigid surface. An 80

meter fall onto an asphalt road is the equivalent of falling approximately 3 meters onto a rigid surface. B-containers have been released from helicopters at a height of 700 meters onto hard ground without suffering any damage.

Results from a series of tests at the Sandia National Laboratory (Ammerman and Bobbe), concerning falls from varying heights up to 36 meter onto a rigid surface according to testing procedures showed that the assumptions on damage and leakage are on the safe side in applicable risk and consequence studies.

Analyses have also been made of fires that last longer than 30 minutes at temperatures higher than 800° C, which could occur even if it is highly unlikely. It should also be pointed out here that the temperature inside the container rises slowly and does not reach the temperature of the fire flamesuntil after several hours. If the fuel cladding is badly damaged and there is ample access to air, an oxidation of the fuel could occur, which would destroy the ceramic structure and would also increase the release of radioactive substances.

Consequently, the risks that a large quantity of radioactive material would suddenly begin to leak out after a collision or a fire are small. There are several reasons for this: the strength and leaktightness of the container, the fact that the fuel is in a cladding and the fact that a greater part of the radioactive substances is contained in the ceramic fuel. Despite the fact that leakage has never occurred, the possibility cannot be completely discounted, a fact carefully taken into account by the transport regulations. Leakage from a transport container is assumed to occur to a greater extent in the event of more serious combinations of mechanical stress and fire, according to an early American risk analysis. The consequences are described in more detail in the section on risk and consequence analyses. Furthermore, if the fuel is encapsulated in a storage canister for final disposal, this provides at least one additional barrier against the dispersion of radioactive substances.

Consequently, the conditions are completely different compared with the transport of e.g. chlorine, ammonia, liquefied petroleum gas, nitric acid and petrol, to name a few of the substances that

have caused severe incidents or accidents in recent years. The barriers between the hazardous substances and the environment, both in terms of number and thickness, constitute an important difference. In the case of railroad tank cars or tanker trucks, the only barrier against the spread of hazardous substances is 1 cm thick walls. The outer barrier alone of a B-container designed for spent nuclear fuel is approximately 30 cm thick. Furthermore, there are no radioactive substances in the form of liquid or gas in decayed spent fuel, with the exception of the inert gas krypton-85, which is quite harmless.

4.6 Preparedness for transport accidents

If an accident were to occur during transport of spent nuclear fuel, the community's regular rescue services are utilised, supplemented by specialist resources from the national radiation protection emergency preparedness organisation. An accident is defined here (and in statistics reported from other countries) as a deviation from normal behaviour. This could include a collision, a truck that has gone off the road or a similar occurrence. The event need not result in leakage or radiation doses for it to be added to statistics and investigated as an accident.

The SOS centres have information as to how they can get in touch with radiation inspectors on duty (TSI's), a resource that the Swedish Radiation Protection Institute (SSI) has on call around the clock. A TSI can offer advice on suitable protective measures and can arrange for radiation readings to be taken at the scene of an accident. These readings can be taken by laboratories with which SSI has contracts in its emergency preparedness organisation and which are located at a number of places throughout the country. If the need should arise for decontamination, i.e. the need to remove or clean from of radioactive material, this can be carried out by the existing specialist organisations, after consultations with SSI. The event of a transport accident involving a B-container filled with spent fuel is highly unlikely and as far as is known today has never occurred. This topic will be taken up in a later section of the

chapter. The competent government authorities are notified in advance whenever spent nuclear fuel is transported.

Sea transport with the ship Sigyn entails comprehensive safety measures. The ship itself fulfils international requirements for buoyancy for vessels designed to carry hazardous materials. If Sigyn were to sink, it is equipped with floatation devices that mark the spot where the ship went down. Special lifting eye bolts are fitted to facilitate salvage. Each B-container is equipped with radio transmitters to signal its position, which facilitates salvaging a container that may have been thrown from the ship when it sank (SKB 1992).

4.7 Swedish experience in transporting spent nuclear fuel

Many years of experience from transporting spent nuclear fuel and radioactive waste have been gained both in Sweden and abroad. The Swedish system of transport by sea on SKB's ship Sigyn is well tested (Dybeck and Gustafsson 1992). It has been in operation since 1983 and transports spent nuclear fuel from the coastal nuclear power plants to CLAB. Nearly 1,000 containers of spent nuclear fuel, the equivalent of more than 2,700 tonnes, were transported between 1985-97.

Spent fuel has also been transported by truck from the now decommissioned Ågesta reactor south of Stockholm, to Studsvik. From there, the containers were taken by road to CLAB. All of these transports were carried out without any ?incident.

4.8 Experience from other countries

At international conferences on transport, reports are submitted dealing with experiences, safety measures and risk analyses in

other countries. A number of current and pertinent reports will be referred to below.

USA

Approximately 2,000 shipments of spent fuel have taken place during the past 30 years, without any leakage or anyone in the general public being exposed to radiation, despite the fact that eight transport accidents involving B-containers for spent nuclear fuel have occurred (Pope 1992). A transport accident in this context is defined as an event that is reported to and registered by a government agency involved, according to certain criteria. The accident does not have to have entailed any damage to the container or any leakage. The containers, as previously described, are designed to withstand severe accidents. Realistic tests at the Sandia National Laboratory in the United States, involving railroad cars or trucks carrying B-containers which have either been driven straight into concrete walls or have collided with each other at high speed, have shown that the containers can withstand this type of stress.

Of the eight transport accidents involving B-containers for spent fuel that have occurred in the United States, half of these involved trains while the other half were on motorways. In 50% of the cases, the containers were empty. Damage that could not be considered trivial occurred in only one case (Chashwell and McClure 1992).

That particular accident involved a truck that went off the road and occurred in 1971 on a motorway in the U.S. This has been described by SKB in a factual report on the transport of spent fuel issued in July of last year. It was also reported on at PATRAM '85. It was also mentioned at last year's meeting of the panel with NWTRB. The accident was caused when the driver of the radioactive transport vehicle was forced to avoid an oncoming vehicle and drove off the road. The rig rolled over and the container was thrown from the trailer. The driver was killed when the cab was destroyed. After several hours of inspection, radiation protection experts could assert that the container was intact and that no leakage had occurred.

Plans to transport spent nuclear fuel (currently being stored at the nuclear power plants) to a repository have been drawn up and reviewed, as mentioned earlier, by NWTRB and others. According to a basic federal criterion, the transport route must be evaluated and deemed suitable.

The panel also brought up the importance of adequate documentation and quality assurance both for the manufacture of the containers and as a basis for licensing.

Great Britain

By the early 1990's, around 13,000 containers of spent fuel had been transported in Great Britain during a period of thirty years. No transport containers had been damaged during this time. Only one derailment had occurred in a railway yard but no damage was caused to the container or to the environment.

During 1984, CEGB, which was the governmental power utility at the time in charge of operating all nuclear power plants, carried out a realistic, full-scale test to demonstrate the durability of the B-container. This was done by allowing a locomotive to collide with a transport container used to transport spent fuel at a speed of 160 kilometres per hour (Mummery and Pannett 1989). The locomotive was completely destroyed and the B-container suffered outer mechanical damage but was otherwise intact.

Germany

Widespread demonstrations have disrupted transports of spent fuel and radioactive waste in Germany on a number of occasions and extensive police actions have been necessary. The level of radiological safety has nonetheless remained high. Spent fuel is transported by train from the German nuclear power plants to reprocessing facilities in France and Great Britain. During the first half of the 1990's, 70-170 freight car loads of spent fuel were transported annually. Return transport of vitrified waste after reprocessing is expected to be carried out in 15 shipments per year

until the year 2003. This will also be done primarily by train (Alter 1995).

France

Detailed statistical information on radioactive transports for the period 1981-1990 has been published by the French authorities (Hamard et al. 1992). The amount of spent fuel that was transported increased from 900 to 1800 tonnes annually during this period. The maximum annual radiation dose to transport personnel during the period was 6 mSv for the transport of spent nuclear fuel. The total annual radiation dose to transport personnel was always lower than 0.01 manSv per year, which is the equivalent of 10 people receiving an extra radiation dose of 1 mSv. For all transport of radioactive material during the period, the combined annual radiation dose for transport personnel was measured at 0.3-0.4 manSv. Previous studies have shown that the total radiation dose to the public is considerably lower than that to transport personnel.

4.9 Consequence and risk analyses

A Consequence analysis in Canada on transport accidents involving spent nuclear fuel

In a consequence analysis from Canada (Kempe 1995), two representative accident scenarios regarding spent nuclear fuel were selected. One scenario pertained to a severe collision combined with leakage while the other dealt with a fire combined with leakage.

The first scenario entailed leakage of some of the actual fuel material that was the equivalent of the maximum amount permitted by design criteria. The material that was assumed to have leaked out was judged to have spread over a 1,000 square meter area of ground, which is the equivalent of one or two normal single-family housing lots. The direct doses of radiation for people at or near the scene of the accident were calculated to be at a level equivalent to the naturally occurring background radiation for one year. As a

result, the consequences were considered to be very small. Pollution caused by the presumed leakage of radioactive material will deposit on the surface of the ground, is not easily soluble and can be easily removed. The probability for this scenario was estimated at 1 chance in 10,000 that this type of incident would occur during a transport period of around 10 years.

The other scenario dealt with the release of caesium from the fuel in connection with a fire. Caesium, which is a solid substance at normal temperatures, can vaporise to a certain extent at the temperatures reached in a lengthy fire since 1-5% typically diffuse to the cladding gap during reactor operation. However, most of the caesium remains contained in the ceramic fuel material and cannot be released at the low temperatures generated in a fire (up to $1{,}000^0$ C). For a larger release of caesium to occur, the temperature must reach at least $1{,}600^0$ C.

Both radiation doses and probability are judged to be lower in the second scenario than in the first.

Many people certainly remember from the Chernobyl fallout that caesium, with its two isotopes Ca 137 and Cs 134, is most dominant in terms of consequences. There is no caesium 134 in encapsulated older fuel which is to be transported to a repository, since it will have decayed. Furthermore, short-lived iodine isotopes, which we were subjected to after the Chernobyl accident, pose no danger since they have basically disappeared before the fuel is transported from the nuclear power plants to CLAB.

A Consequence Study of a shipwreck involving Sigyn

Consequence analyses of potential shipwrecks have also been carried out in Sweden. Studies of sea transport were made in the late 1970's (Appelgren et al.) and early 1980's (Olsson et al.) ahead of the establishment of SKB's sea transport system. Various accident scenarios were analysed, e.g. a damaged and leaking transport container with spent fuel was lost in the Baltic Sea at a depth of 100 meters and could not be salvaged. The doses of

radiation, primarily in the form of consumption of fish, were conservatively estimated and was in fact at most 0.03 mSv over a 50-year period for the most exposed group. The normally occurring background radiation during the same period is approximately 100 mSv.

Risk studies

A survey of published studies of transport risks was reported (Blenkin et.al. 1995) at PATRAM '95. Eighteen studies had been analysed in detail. A number of the studies expressed risk in the same terms – the number of fatalities per transport kilometre - and made a comparison with several other types of hazardous materials. One of the conclusions showed that the risks in general were lower for the transport of radioactive material than for other hazardous materials. There was no general difference in transporting hazardous materials by truck or by train. The advantages/disadvantages of transporting spent nuclear fuel by road or by rail are discussed in NWTRB 1997.

An early American (NRC 1977) risk study shows that the non-radiological injuries, i.e. normal bodily injuries, burns and fatalities that can occur during all types of transport far outweigh the risks attributed to the radioactive content.

4.10 Summary

The transport of spent nuclear fuel has increased for the past thirty years or more in a number of countries without exposing personnel or the public to any significant levels of radiation. The high degree of safety has been achieved through rigorous international safety requirements for this type of transport. The requirement that the material be shielded by an outer steel casing on the transport container that is several decimetres thick, which is necessary to protect against direct exposure to the intense radiation from the

fuel, also provides a natural protection against collision and fire damage during transport.

The conditions that could lead to the spread of radioactive material after a transport accident involving spent nuclear fuel are very limited. In addition to the thick outer barrier with a bolted cover and sealing rings in the transport container, possible leakage is also limited by the fuel cladding and by the ceramic fuel material itself, in the event of a fire or a collision. If the fuel is also enclosed in a canister designed for deep disposal, one or actually two additional barriers are added that help prevent the release of fuel into the environment. There is no known experience of leakage having occurred during the transport of spent fuel. Studies of the possible consequences after a collision and fire assume, however, that leakage will occur from the transport container.

Extreme and hypothetical damage has also been analysed. Studies in different countries show that the transport of radioactive material, including spent fuel, is much safer than the transport of other hazardous materials. Even in the case of extremely severe transport accidents, the radiological consequences will be minor or non-existent.

References

Alter U.
Summary of nuclear material transport in the Federal Republic of Germany 1990-94
PATRAM ’95 p 584-591

Ammerman D.J., Bobbe J.G.
Testing of the structural evaluation test unit
PATRAM ’95 p 1123-1130

Appelgren A., Bergström U., Devell L.
Stråldoser vid haveri under sjötransport av kärnbränsle
KBS TR 57 (1978)

Blenkin J.J. et al.
A literature survey and review of transport risk assessments
PATRAM '95 p 893-901

Chashwell C.E., McClure J.D.
Transportation accidents/incidents involving radioactive materials 1971-1991
PATRAM ' 92 p 1076-1082

Dybeck P. , Gustafsson B.
A decade of successful domestic sea transports of radioactive waste in Sweden 1982-1992
PATRAM '92 p 211-218

Hamard J. et al.
Estimation of the individual and collective doses received by workers and the public during the transport of radioactive materials in France between 1981 and 1990.
PATRAM '92 p 67-73

IAEA
Regulations for the safe transport of radioactive material. 1985 Edition (As amended 1990)
IAEA Safety Series No 6 (1990)

IAEA
Regulations for the safe transport of radioactive material. 1996 Edition
IAEA Safety Standards Series No ST-1 (1996)

Kempe T.F.

An examination of environmental contamination following a hypothetical used-fuel transportation accident
PATRAM ‘95 p 931-938

Mummery C.B., Pannett R.F.
Ten thousand movements of irradiated fuel from CEGB power stations - Review of recent experience.
PATRAM ’89 p 1109-1114

NWTRB. US NUCLEAR WASTE TECHNICAL REVIEW BOARD
Meeting of the panel on the waste management system, spent fuel transportation safety
NWTRB November 19-20, 1997. Transcripts by e-mail.

Olsson G., Sundblad B., Devell L., Edlund O.
Radiologiska konsekvenser vid förlust av behållare med använt kärnbränsle vid sjötransport
Studsvik NW-82/348, 1982

PATRAM ‘92
The 10th International Symposium on the Packaging and Transportation of Radioactive Material. September 13-18, 1992 Yokohama City, Japan

PATRAM ‘95
The 11th International Symposium on the Packaging and Transportation of Radioactive Material. December 3-8, 1995 Las Vegas, USA

Pope R.B. et al.
Historical overview of domestic spent nuclear fuel shipments in the United States.
PATRAM ‘92 p 121-128

SKB
Transportsystem för använt kärnbränsle och radioaktivt avfall.

Systembeskrivningar
SKB 1992

SKB
Förstudie Malå. Transportmöjligheter till ett djupförvar i Malå kommun
SKB PR D-95-004 (March 1995)

SKB
Förstudie Nyköping. Anläggningsutformning, bemanning och transportmässiga förutsättningar
SKB PR D-96-022 (Sept 1996)

5 Safety analysis of the final disposal system

5.1 Background

The Government stated its opinion on safety assessments of the final disposal system in its decision after SKB submitted RD&D 92 Supplement. The Government noted that "decisions concerning the construction of the planned encapsulation plant may involve considerable commitments with respect to future handling and storage methods. Thus, as far as can be assessed at this stage, these decisions should not be made until a safety assessment of the entire final disposal system is presented and the planned final disposal method has been shown to be suitable." The Government stated that an integrated safety assessment (system analysis) should be submitted as a basis for applications for permission to construct the planned encapsulation plant.

Residents in the municipalities where SKB is planning or has conducted feasibility studies for the siting of a repository have attached considerable importance to the question of whether a repository is safe or can entail serious risks to them or to future generations. The issue of spent nuclear fuel disposal has also been brought up by those who question the future of nuclear power in Sweden. Safety assessments of the final disposal are therefore important at several levels – for the Government, for the central and local authorities, for communities in the municipalities involved in the siting of different facilities and for those who otherwise involve themselves in issues relating to the future of nuclear power.

Safety analyses of a repository for nuclear fuel at a great depth in Swedish bedrock have also been made on several occasions, by SKB as well as SKI. These safety analyses have been documented as technical reports with detailed descriptions of the knowledge base, calculation methods and results. Many people consider these reports to be difficult to understand.

During 1997, KASAM arranged two seminars. The seminars focused on bridging the gap between the requirement for comprehensiveness and scientific correctness in the reporting of the safety analysis to the competent authorities, and the requirement for comprehensibility of the safety analysis to laymen wishing to form an independent opinion of the safety of the final disposal system. This chapter is based on material which was reported at these seminars and on impressions from the discussions to which most of the time in the programme was devoted. Those involved in the discussions spent most of their time on questions relating to the demands and the comprehensibility of the safety analysis, rather than on questions relating to radionuclide speciation, distribution coefficients and darcy flows. Nevertheless, these items also have a place in the safety analysis. Therefore, some of the ongoing work on safety analysis is also described as a background to the current situation.

5.2 The task of the safety analysis – to show whether what is hazardous is also a risk

Spent nuclear fuel is hazardous. It contains radioactive substances which emit ionising radiation. It is dangerous to handle or to be in the vicinity of a fuel element that has been removed from a reactor, unless the fuel element is encapsulated in a thick-walled container or has been placed far below the surface of a storage pool. Radioactive substances become particularly hazardous if they accumulate inside our bodies through ingestion or inhalation. However, the fact that radioactive substances in spent nuclear fuel

are hazardous does not necessarily mean that spent nuclear fuel is a hazard to humans and to the environment. If the fuel is enclosed in a sufficiently thick radiation shield and the radioactive substances are sufficiently well contained, then the fuel will not be a hazard to humans or to other living creatures during any of the handling stages.

It is the purpose of the safety analysis to demonstrate how efficiently the radioactive substances in the fuel can be shielded and contained and how robust and how permanent this protection can be expected to be. The safety analysis must also show the risks which will arise if the integrity of the protective barriers is breached. Is the risk of final disposal that the environment surrounding the repository will be contaminated by radioactive substances to as great an extent as the most exposed areas after Chernobyl? Or is the risk about the same as the risk that the biosphere in Sweden is always exposed to through the release of radioactive substances from the bedrock through erosion and weathering?

5.3 The use of safety analyses

SKB as well as the regulatory authorities need to analyse the performance and safety of the final disposal system.

SKB needs to conduct assessments in several stages, from the first design proposals through the continued research and development programme and up to the operation and closure of the repository. During the first stage, the analysis is used to give the designer an idea of the properties of the planned repository, to show how the parts interact and the ability of the combination of protective barriers to isolate the radioactive substances from the environment.

At this early stage, knowledge is incomplete in many respects. Reasonable assumptions have to be made about the properties of the barriers based on previous experience of the bedrock and of the materials in the engineered barriers. The research programme

is guided by the analyses since the analyses show the gaps in knowledge that must primarily be filled.

During the development work, variations on and alternatives to the original design concept are analysed and compared. This will allow SKB to assess whether the road it follows can ultimately lead to the goal.

When the development work reaches the implementation stage - site investigations and prototype barrier fabrication - safety assessments will be needed as a basis for requirement specifications with respect to the bedrock and the engineered barriers.

The application for permission to construct facilities must include an assessment of the safety of the entire final disposal system since the different stages of handling: encapsulation, possible interim storage, transport and deposition each entail requirements which must be met, at the same time that they lead to a long-term safe final disposal.

SKI must also, in good time, start its own safety analyses in order to be able to form an independent view of the requirements with respect to the whole final disposal system and individual barriers as well as to have its own basis for a judgement of compliance in order to evaluate licence applications from SKB at different stages.

5.4 How to analyse the future? Scenario methodology

The assessment of the safety of a final disposal system must deal with the deposition stage when the spent nuclear fuel is deposited together with the buffer material in prepared positions in the bedrock as well as the further development of the repository after closure. Full-scale testing of the deposition of the fuel can be carried out in the prototype facility which SKB will set up at the Äspö Hard Rock Laboratory. This work will be carried out using canisters and a buffer that is of the same design as that of the

actual repository. Although the canisters will not contain radioactive fuel, the assessment of safety in connection with deposition will still be based on an adequate basis of experience.

The long-term development of the repository cannot be studied in advance in the same way. SKB is planning to construct the repository in two stages. In the first stage, 5-10 % of the fuel will be deposited. The repository will be kept open for inspections and measurements for a period of time that has not yet been determined, maybe a few decades. The value of such a period of observation should not be underestimated. It can lead to a valuable confirmation of the calculated temperatures in the near field, since the temperature changes most quickly directly after disposal. It also makes it possible to conduct random checks of how the buffer is affected by the heat from the fuel and by the groundwater. However, an observation period cannot be prolonged so as to provide decisive information on the development over a period of thousands of years.

Long-term safety is assessed on the basis of assumptions concerning the future development of the condition of the barriers and external conditions, especially the climate. Such an assumption, which is called a *scenario*, is described in as much detail as is necessary for calculations of the consequences of the assumption for safety. No one can claim to be able to fully predict all future developments. However, a thorough inventory of possible developments and events is still warranted. Scenario analysis can be used to design a final disposal system that is so robust that it can withstand the future stresses that we can predict, to the extent that we consider to be justified. However, a safety assessment cannot help to determine the size of the resources that must be invested by our generation to forestall damage which may, hypothetically, be caused to future generations. How the precautionary principle should be applied to the results of the safety assessment is ultimately a political decision.

The assumption of the future which is closest to hand is that the bedrock and climate will continue in their present condition. This assumption is used by both SKI and SKB as a premise for the long-term assessment. The assumption will agree with reality for

some time after the closure of the repository, but at most for a few thousand years. Although the bedrock changes very slowly, the climate will change considerably within thousands of years.

Climate researchers and quartenary geologists have no doubts concerning climatic changes over the next hundred thousand years. Our climate is heading towards a new ice age. If it develops along similar patterns as the last ice age, it will start with a slow cooling until Siberian conditions, with deep permafrost and tundra vegetation, occur in 5 to 10,000 years. The glaciers will form an ice cover, culminating in about 20,000 years, 60,000 years and 110,000 years. Between the culminations, the ice cover may retreat although the climate will still be considerably colder than at present. A warm period, such as that at present, is not expected to occur until about 120,000 years.

A safety assessment with a longer time horizon than a few thousand years must, therefore, include at least one ice-age scenario. SKB's Technical Report 91-32, "SKB/TVO Ice-age scenario", and SKI Site-94, Chapter 9.3.2 provide two examples. The ice-age scenario must provide a detailed description of how permafrost will spread over the country, how it will be followed by an advancing ice front, how land surfaces will pressed down by the ice cover and then rise again once the ice has retreated – temporarily or ultimately. It must also show how all of these changes can affect the formation and turnover of groundwater in the bedrock. The time-scale does not have to be exact. The important factor is to be able to describe the major changes which can occur in the bedrock during an ice age. Exactly when they occur is less important.

Detailed data are available for such a description of the coming ice age. Greenland and the Antarctic are now undergoing such an ice age. The last ice age has left many traces in Scandinavia and on the seabeds around the world. These traces can be interpreted by various methods so that the researchers can describe the most important features of the last ice age. It is assumed that the coming ice age will largely resemble the last one which, in the case of Sweden, ended about 10,000 years ago.

Current climatic conditions, succeeded by an ice-age scenario, make up the central scenario, according to SKI's terminology, in its long-term safety assessment. A number of other scenarios are linked to this scenario which are illustrations of what may happen rather than forecasts of what will happen. These scenarios may include the occurrence of an earthquake at a greater or lesser distance from the repository or drilling or blasting in the bedrock hosting the repository some time in the future when no one remembers or can find out about the radioactive waste buried below. These rather speculative scenarios cannot be selected on the basis of what we know about the future but on the basis of what we consider to be reasonable to include in the calculations.

Furthermore, under the heading of "scenarios", the consequences are analysed of possible defects which, in spite of manufacturing control, can occur in individual items of series-manufactured products such as fuel canisters and bentonite blocks.

Within each scenario, e.g. the earthquake scenario, different calculation cases may have to be analysed. A calculation case is one assumption among several possible assumptions, e.g. concerning the magnitude of the earthquake and its proximity to the repository.

5.5 Regulatory requirements on safety analysis

SKI has described its premises for regulations concerning safety in connection with the final disposal of spent nuclear fuel in SKI Memorandum 97017. These premises include "General requirements on the safety assessment of the long-term performance of a repository". The requirements apply to:

- time-scales and the general direction of the assessment,
- scenarios and models as well as
- how different types of uncertainties will be treated in the safety assessment.

SKI maintains that repository performance must be analysed for periods which extend over hundreds of thousands of years and more.

The performance of the barriers in the repository must be analysed on the basis of how they are affected by two groups of factors – external processes such as climate changes and their consequences as well as internal processes, such as properties of the engineered barriers including reasonable assumptions concerning manufacturing defects and other imperfections.

The safety assessment must also take into consideration uncertainties and variations in external and internal processes.

A safety analysis must describe a set of scenarios which, as far as possible, covers all of the external events which can affect the future performance of the repository. This includes models which adequately describe the processes, e.g. fuel dissolution and radionuclide transport. Several different approaches should be used, if possible, to provide as comprehensive a view of risk and safety as possible.

5.6 Content of the safety analysis

Overview

The repository must isolate the radioactive substances in the spent nuclear fuel from our living environment. The first means of achieving this is to deposit the fuel at a great depth in the bedrock. From this position, the radioactive substances can only be carried to the surface through major faults in the bedrock, via groundwater transport or by being retrieved by humans. Faults on the scale of hundreds of meters do not occur in Swedish bedrock, during the current geological period. Human intrusion is a risk which cannot be eliminated in the repository design since a repository that can be filled can also be emptied of its contents. However, the transport of radioactive substances by the groundwater can be delayed or prevented if the fuel is surrounded by barriers which block the groundwater flow (see Figure 5.1).

1. Uranium dioxide pellets encapsulated in a zircaloy cladding. Not easily dissolved. Delays the leaching of radionuclides if the canister becomes filled with water.
2. Insert of solid cast iron. Delays the penetration of water if a hole should occur in the copper canister.
3. Copper canister. Prevents water from penetrating as long as it is leaktight.
4. Bentonite buffer. Prevents the groundwater flow from reaching the copper canister. Limits and delays radionuclide leakage.
5. Bedrock. Transports radionuclides in fissures with the groundwater flow. Several radionuclides are delayed during transport since they adhere to the fissure walls for a long or short time. All radionuclides are diluted.

Figure 5.1: KBS-3 system barriers

Therefore, the safety analysis is largely focused on the description and calculation of the groundwater's capacity to penetrate the barriers and to then transport radioactive substances from the fuel to the biosphere. These processes are described most simply and clearly if the repository and its surrounding environment

are divided into three parts which have different functions. The first is the engineered barriers. The function of these barriers is to contain the radionuclides so that they do not reach the bedrock. The second is the bedrock surrounding the repository. The bedrock cannot keep the radionuclides since it contains mobile groundwater which can transport the radionuclides, but it can delay and dilute them. The third is the biosphere, where the radionuclides are distributed between sediment in wetlands, surface water with the sea as the final destination and groundwater. Wetlands can dry out and turn into arable land, animals in watercourses can become a part of our food chain and the groundwater can be drawn off through wells for household use or for crop irrigation. These are some of the pathways of the radionuclides from the groundwater to man.

In the safety assessment, mathematical models are made of the various processes. However, the models are based on a detailed description of the processes. Consequently this account of the safety analysis of spent fuel disposal is in the form of a description of the most important properties of the three parts of the repository, rather than a description of the mathematical models. The description is based on the design of a repository with its barriers as described by SKB in RD&D Programme 95.

Figure 5.2: Possible design of the canister and insert.
(Source SKB).

The engineered barriers

The fuel canister

The innermost barrier is the leaktight fuel canister, figure 5.2 (SKB SR 95 fig 5.3-2), fabricated of material which can withstand the groundwater under the conditions prevailing in the deep bedrock. In its present design, it consists of a cast and welded, cylindrical insert of steel with vertical, square-shaped channels where the fuel

bundles are inserted. Once the fuel is inserted, the insert is sealed with a flat lid which is fastened by bolts.

The steel insert is enclosed by a 5 cm thick copper canister with a welded base plate and lid. There must be a gap when the insert is lowered into the canister during assembly. The gap disappears when the canister is exposed to external overpressure from the groundwater and the surrounding bentonite once the repository is closed. The copper is sufficiently soft to be pressed against the insert, thereby eliminating the gap between the steel and the copper.

A canister designed along these lines functions as two barriers, the copper canister and the steel insert, each of which is an important barrier against ingress of water into the fuel channels.

The bentonite

The canister is deposited in a vertical, drilled pit. A layer of bentonite is packed around the canister. Bentonite is a clay which swells when it comes into contact with water. In the pit, the clay cannot expand beyond the available space. The clay particles continue to expand but the swelling causes the clay to be more densely packed, causing it to become practically watertight, even though it contains water. The water molecules move around in the microscopic pores that exist in the densely packed clay, a movement called diffusion, but the water does not flow through the clay. In this way, the bentonite clay protects the canister from harmful contaminants which could exist in the groundwater outside the bentonite. Since compact but moist bentonite is somewhat plastic, it will equalise the local stresses that would arise if the walls of the pit were to be displaced due to a bedrock movement.

The canister and bentonite, a long-term partnership

The most valuable time from the standpoint of safety is the time during which the copper canister is leaktight. As long as there are no penetrating holes in the copper, the water in the bentonite

cannot reach the steel insert and the fuel and no radioactivity can escape. However, there may be defects in the canister from the fabrication process, since there are limits to the size of the defects that can be detected when the fabricated canisters are inspected. There is also the possibility that the copper may crack when pressed against the insert.

If for any such reason, a moderately large hole penetrates the copper, water will come into contact with the steel insert. A chemical reaction will start between the water and the steel. The steel will corrode or rust, as it is most familiarly known. Water is used up in the corrosion process and hydrogen gas is formed. The hydrogen gas will cause pressure to build up within the canister. The water will be pressed through the bentonite as long as the groundwater pressure outside exceeds the gas pressure inside. Once the pressures are equalised water continues to be supplied to the canister by diffusion through the bentonite which is a slow process. Hydrogen gas production will continue for as long as there is water or water vapour inside the canister. Sooner or later, the corrosion will also cause holes to form in the insert so that water can penetrate into the fuel channel. However, since water is, at the same time, used up in the corrosion process, it can take a long time before the fuel channels become filled with water.

The length of time this will take will depend on the size of the hole in the canister, how much water leaks in towards the hole through the bentonite, how rapidly the steel rusts, the degree to which the rust blocks water passages, thereby preventing further corrosion, and the leakage routes of the hydrogen gas and the water into the fuel channel. Finally, the rust, which will take up more volume than the steel from which it is formed, will cause the insert to swell, the copper canister to stretch and the passages to the bentonite to expand. Work is in progress (reported in SKB Technical Report 97-19) to make calculation models of all of these processes so that they can be included in the safety analysis.

Like water, the radionuclides cannot flow through the bentonite. They move, diffuse, very slowly in all directions in the water in the network of microscopic pores in the clay. Certain radionuclides adhere for a short or a long time on the clay particles while others

move more or less unrestricted in the water or along the clay particles. However, since they disperse in all directions, they spread through the bentonite mass like a cloud until they reach the outside. Adequate calculation models exist which describe this diffusive movement through the bentonite in its original condition, e.g. SKB Technical Report 91-33.

However, with the new canister design, the previous calculation models of the integral performance of the canister and bentonite are no longer applicable. The hydrogen gas pressure inside the canister will continue to increase until it is as high as the pore water pressure in the bentonite which, in turn, is equal to the groundwater pressure plus the swelling pressure of the bentonite. The hydrogen gas will then press through the bentonite and this will continue as long as hydrogen is produced. The detailed gas transport process and how it will affect the radionuclide leakage have not yet been determined.

The leakage of radionuclides from the bentonite to the surrounding bedrock can be specified in terms of grams per year or Becquerel per year, and is different for different radionuclides. These quantities give an indication of how well the engineered barriers fulfil the function of isolating the radioactive substances from the surrounding rock and ultimately the biosphere.

The bedrock

Once they have escaped from the bentonite, the radionuclides will enter fissures in the surrounding rock (or move to the more porous backfill at the top of the pit). In the fissures, the radionuclides will alternately be dissolved in water and stick to the fissure walls. Microscopic fissures also exist in the fissure walls where some fraction of the radionuclides will penetrate and never leave or will leave after such a long time that their activity will be significantly reduced. Therefore, the radioactive substances move more slowly through the rock than the groundwater. How much more slowly? This is difficult to measure since the transport times are measured

in thousands of years while direct measurements to find an answer can only be conducted for a few decades. However, experiments are in progress at the Äspö Hard Rock Laboratory to obtain more certain information on this important issue.

Besides the fact that the radionuclides decay as they are transported, they are gradually diluted as groundwater from fissures near to the canisters leak into major groundwater veins.

The assessment of the bedrock's contribution to safety cannot be made with the same level of reliability as the assessment concerning the canister and buffer, since the length, breadth and width of the different fissures cannot be measured in the same way that the canisters and buffer can be measured and checked. Instead, measurements are made of fissures within a limited number of points in the bedrock. During a site investigation, boreholes are drilled from the ground surface, in a subsequent detailed characterisation they are also drilled from tunnels at the repository depth. Using these measurement data and other observations, a model of the fissures in the bedrock can be created. This includes the lengths and angles of the fissures and the variation in their properties. An entirely accurate model cannot be made. To do this, boreholes would have to be drilled everywhere in order to determine the appearance of the fissures everywhere. After such an investigation, it would be preferable not to use the bedrock to host a repository. However, the model does not have to be correct in all details in order to be used for a safety assessment.

SKB can make sure that canisters are not deposited across or very near to a water-bearing fissure when the repository is constructed. However, SKB will not know how far it is from each canister to the nearest fissure. The important factor is that the safety assessment should include the variation in the distance between canisters and fissures which will exist in reality as well as the variation in the properties of the fissures which will also occur in reality. The detailed characterisations will provide random data which will be processed statistically. Using these methods, it is possible to determine the range of the variations in distance and fissure properties which must be included in the calculations in order to be on the safe side. Calculations are then repeatedly made

to cover these variations. SKI Site-94 describes the results of an extensive assessment of radionuclide transport through the bedrock in accordance with this principle.

In this way, the contribution of the bedrock to the repository performance and safety can be calculated in spite of the fact that the bedrock cannot be measured, inspected and described in a detailed and accurate manner.

The biosphere

Close to the ground surface, the groundwater becomes a part of the biosphere. Groundwater emerging from great depths normally flows out at low points in the terrain or into a water course or directly into the sea. In Sweden, with its high groundwater levels, the low points in the terrain are often wetlands, lakes or swamps. The radioactive substances can stick to bottom sediments or follow the water course out to the sea. On the way, they can be taken up by aquatic plants or animals in our food chain. Before the groundwater reaches the ground surface, it can also be drawn off by wells for household use or irrigation. The supply of radionuclides to the biosphere can be converted into radiation doses, if it is assumed that future populations will eat and drink as we do now and if data are available concerning the uptake of different radioactive substances in nature by plants and fish which are used as food.

In Chapter 14 of its Site-94 report, SKI reports such calculations of biosphere-related factors expressed in Sv/Bq, for all of the important radionuclides in the nuclear fuel. The analysis was made by SSI together with SKI and applies to a repository siting at Äspö which SKI selected as the basis for Site 94, since there were extensive bedrock data from that site. The calculations show that the largest part of the radiation dose for most radionuclides is obtained from drinking water drawn from a water vein that transports radioactive substances released from the repository. It is easy to dismiss as meaningless a radiation dose calculation that uses our current lifestyle as a basis for calculating radiation doses in thousands of years' time. However, when it is drinking water

which is responsible for the dominant part of the dose, the calculation cannot be said to be completely without forecasting value.

As a complement to dose limits which must be based on a biosphere assessment, SSI has considered establishing limits for the estimated supply to the biosphere of radionuclides with different properties, alfa and beta emitters. Such radioactive substances are supplied to the biosphere in a natural way through the weathering of the minerals in the bedrock. The average extent of this supply over time is known. If the supply of radionuclides from a repository is some fraction of the natural supply, the living conditions for organisms in the biosphere, including humans, should not be affected in any significant way.

5.7 What needs to be done in the further work on safety analysis?

A premise for further work on safety analysis is SKI's safety assessment requirements which are still under discussion. The requirements concern the time range, scenarios, models and uncertainties.

The time range. Should we be more concerned about our age and less about the ice age? Can any reduction of the decision basis be justified?

SKI maintains that the repository performance must be assessed for times which extend beyond hundreds of thousands of years and more, even up to millions of years. A calculation of a repository's radioactive inventory over such a long period of time is possible solely because radioactivity, unlike almost all processes in and on the Earth's crust, is not affected by any external factors such as pressure, temperature or chemical changes. The size and composition of the radioactive inventory can be used as a measure of the hazard which the spent fuel constitutes. Depending on the risk comparisons made, it can be concluded that the fuel no longer constitutes a significant risk once the radioactive inventory has decayed below some limit.

This is not only a question of the comprehensiveness of the safety analysis as a basis for decision-making. One question which is equally as important is how far into the future do we want to extend our responsibility for what we do now?

According to all of the climate experts, Sweden will undergo a new ice age which will erase all traces of the present society, except possibly hazardous waste repositories. Are we responsible for all of the consequences of our actions up to the coming ice age? Do we have to feel responsibility for those who will recolonise the country after the next ice age? If we consider that calculations of possible radionuclide releases after the coming ice age or in an even more remote future should be included in the basis for decision-making, will the decision be a better one, because of that? Should we allow our choice of method, site and costs for a spent nuclear fuel repository to be affected by differences in calculated but nevertheless hypothetical risks after a new ice age? The same questions can be raised concerning other toxic elements that we extract from ore, use in our society and finally must get rid of in some way. There is need for an ethical discussion concerning the issue of our long-term responsibility. However, it has a broader application than merely the final disposal of spent nuclear fuel, see Chapter 1 of this report.

Scenarios

SKI maintains that a safety assessment must describe a set of scenarios which, as far as possible, cover such internal and external events which can be expected to affect the future performance of a repository. The need for scenario analysis is indisputable. Internal events involving materials left behind or forgotten in the repository must be analysed due to their importance for the regulations for work at the facility. External events such as new ice ages or bedrock movements must be analysed to provide a basis for designing the engineered barriers so that they are robust enough to withstand stresses which we expect will arise. Other external events such as human intrusion in the host bedrock for some purpose are more speculative. How much importance should be attributed to analyses of such speculative events as a basis for decision-making?

A less speculative scenario was discussed at the seminar. It can go against the grain to make an irrevocable decision concerning the disposal of spent nuclear fuel, especially if Sweden is one of the first countries to make such a decision. It may be hoped that another, much better course of action will manifest itself if the decision is postponed for a while. This would mean that the current interim storage would have to be prolonged. This can be done by continuing the activities at CLAB or through interim storage in a deep repository. In the latter case, the deep repository would be prepared and the fuel deposited on a demonstration scale or in full, but the repository would not be closed. An open deep repository would entail different conditions in terms of groundwater chemistry and flow and in terms of the bentonite buffer's ability to take up water compared with a closed repository. An open repository would also entail a greater risk of intrusion and repository contamination. A safety assessment of extended interim storage would have to be conducted, regardless of the storage method, in order to establish whether we should rely more on the stability of society and human beings in the perspective of one hundred years than on the stability of the bedrock and canisters in the perspective of one hundred thousand years.

Models

Models must be created which adequately describe the processes in the repository. The most severe limitation of the safety analyses which have so far been carried out has been the lack of a final canister design to model. Consequently, the analyses have started with an assumption that, at some time, a hole, of an assumed size, appears in the canister and that the canister becomes filled with water within a short time. This has been the premise for the calculation of radionuclide leaching, diffusion of waterborne radionuclides through the bentonite buffer, transport in mobile groundwater through the bedrock and transfer of radionuclides to man via different pathways through the biosphere. The initiating stages, the processes which can cause holes to occur in the canister and water to fill the fuel channels, resulting in radionuclide leaching, have not been included in the assessment.

As described in "The engineered barriers" above, the latest canister design provides completely new conditions for the analysis. A penetrating hole in the copper canister does not primarily lead to the canister filling up with water but to corrosion of the steel canister inside. During the corrosion process, water is used up and hydrogen gas is formed. The filling of the fuel channels in the canister with water will be delayed. The hydrogen gas will leak out through the bentonite when the pressure is sufficiently high. These processes will be of considerable importance for radionuclide leaching from the fuel as well as leakage to and through the bentonite. However, current knowledge of all of this is hardly sufficient as a basis of a new calculation model. Experiments with and measurements of a model or prototype of the canister and the bentonite in the pit will have to be performed before a new safety analysis is carried out.

Uncertainties in the safety assessment

The safety analysis must include uncertainties and variations with respect to future conditions in the repository surroundings and the properties of the engineered barriers and bedrock. Uncertainties are included in the analysis and they have been given such a

prominent place that the impression may be given that the safety analysis mainly consists of uncertainties. To understand safety, it is important to examine in detail what the term "uncertainty" means in different contexts.

Uncertainties concerning future releases or radiation doses from the repository can, in simplistic terms, be classified into two categories: uncertainties about future events and processes and uncertainties in the calculation data.

Uncertainties in the calculations due to deficiencies in the data can be treated using established methods. The significance of such uncertainties can be estimated and reported as margins of error or as limits between which it is highly probable that the future releases or radiation doses will lie.

The significance of uncertainties about future events and processes can be limited through the design of the repository. The siting of the repository at a great depth in the bedrock, which reduces the impact of future climatic changes, is one such measure.

Each event sequence or chemical or physical process that cannot be calculated with reliable uncertainty margins must be evaluated particularly with respect to its significance to the safety assessment as a whole. It may be possible to disregard certain processes because they cannot affect the result of the analysis beyond the margins of error which already exist. Further research can make it possible to calculate other processes so that they can be included in the analysis. However, processes and especially future event sequences may remain of which it is impossible to gain adequate knowledge and which cannot be eliminated on the basis of being relatively insignificant.

Due to such residual uncertainty, actors and decision-makers within the area can be tempted to postpone decisions regarding final disposal in the hope that the residual uncertainty will decrease with time through new research findings. However, they must balance postponing the decision against the uncertainties which a continued interim storage for an indeterminate period may entail in terms of maintaining comprehensive competence of the practical problems of final disposal and of the commitment and willingness of

future generations to allocate funds to resolve the problems that we have passed on to them. There is no guarantee that the residual uncertainties will decrease as time goes by.

5.8 Summary

The task of the safety analysis is to show how effectively the radioactive substances in the spent nuclear fuel can be shielded and contained as well as to show how robust and durable this protection can be expected to be. The analysis must also show the risks that could arise if the protective barriers are breached.

The analysis must extend far into the future. No one can claim to be able to fully predict future developments. However, a thorough inventory of possible developments and events is warranted as a basis for the design and siting of the repository. This analysis takes the form of a scenario analysis. Various assumptions are made concerning the future development of the barriers inside the repository and of external events, especially the climate.

An important question is how far into the future our responsibility for the final disposal should extend. Sweden will undergo a new ice age, which will erase all traces of the existing society. Should we feel that we are responsible for those who may re-colonise Sweden after the coming ice age? Do we have to assess the performance of the repository hundreds of thousands of years into the future and should we allow the method and site selected for a repository to be affected by differences in estimated but yet hypothetical risks in a remote future? The same questions can be raised with respect to other toxic elements that we extract from ore, use in society and must ultimately get rid of in some way. We need to discuss the temporal scope of our ethical responsibility (see Chapter 1). However, such a discussion has a broader application than merely the final disposal of spent nuclear fuel.

The description of the safety analysis is based on the design of the barrier system which SKB reported in RD&D Programme 95. The current canister design is different from previous designs in

that now, more than before, the design functions as two barriers – the copper canister and the cast steel insert which will keep the fuel in place. The copper canister will prevent the groundwater from penetrating into the fuel as long as it is leaktight. If a hole should penetrate in the copper canister, the cast steel insert will delay the ingress of water since steel uses up water during the corrosion process (rusting).

Since the groundwater cannot flow through the bentonite but can only diffuse into and through the bentonite, the supply of water to a hole in the copper canister will be insignificant. Corrosion will occur relatively slowly. It may therefore take a long time for the canister to become filled with water, even if holes of a moderate size should penetrate the copper at an early stage.

On account of the new canister design, previous analyses of the engineered barriers are no longer applicable. It must be possible to describe the integral performance between the canister and the bentonite in the form of a calculation model. However, current knowledge is not sufficient as a basis for such a model. Before a new safety analysis can be performed, experiments and measurements of a canister prototype and the bentonite in the pit must be conducted to obtain reliable data for a new calculation model.

References

1. SKI Projekt-90. Vol I and II. SKI Technical Report 91:23

2. SKB 91. Final disposal of spent nuclear fuel: Importance of the bedrock for safety: SKB Technical Report 92-20 May 1992.

3. SKB SR 95. Template for safety reports with descriptive examples. SKB Technical Report 96-05.

4. SKI Site-94. SKI Report 97:5.

5. SKB Technical Report 97-19. Assessment studies for a copper canister with cast steel inner component. Alex E Bond et al, AEA Technology, Harwell, UK. May 1997.

6 Fractures in bedrock

6.1 Introduction

In the search for a suitable site for a repository for spent nuclear fuel in Sweden, the idea of using Swedish bedrock was presented in the 1970's. Since then, a great deal of research has been done to characterise the bedrock as a barrier around the planned repository. The occurrence and characteristics of individual fractures and fracture zones have been a central point of interest in this regard.

Ideas on the characteristics of a suitable site in terms of geographic and topographic location, bedrock, depth and location in relation to surrounding fracture- and deformation zones, etc have evolved over the years. The objective from the beginning was to find a sufficiently large volume of "fracture-free" bedrock. Afterwards, the "plinth model" evolved, i.e. the objective became to find a homogeneous slab of bedrock, protected by surrounding planes of weakness that would absorb future movements in the Earth's crust.

6.2 The formation of fractures

The upper layer of the Earth's crust can be considered to be brittle but at a depth of 15-20 kilometres the bedrock in the Earth's crust in Sweden (at approximately 200-400° C), becomes a soft, viscous mass. In a brittle crust, the deformation exceeds the limit of the bedrock's elasticity, leading to mechanical cracks that create

dislocations (fractures). The characteristics of the crust change at greater depth, where the minerals composing the crust become successively more malleable. This type of "softer" deformation of the bedrock makes mechanical cracks less likely to occur and pores are not formed. Rock is composed of different minerals in varying proportions with quite different physical characteristics. For this reason, the dividing line between brittle and plastic behaviour varies from one type of rock to another. The time factor also plays a decisive role in determining whether or not fractures form. If stress forms quickly, it can consequently also lead to cracks at great depth. Registered earthquakes, which can be seen as independent proof that movement has taken place, have however, occurred in the upper layers of the Earth's crust in Sweden in modern time.

As long as isotropic (equal along all axes) stress conditions exist in the bedrock or as long as the limit of the bedrock's elasticity has not been exceeded, no fractures will occur. On the other hand, if the stress in the bedrock is anisotropic, i.e. when stress (compressive stress or tensile stress) is greater on one axis than on another, the bedrock deforms in an attempt to recreate isotropic stress conditions. If the limit of elasticity is exceeded, a permanent deformation of the bedrock will occur through plastic deformation and brittle cracks. How the bedrock deforms depends on the surrounding physical parameters such as pressure, temperature and the physical characteristics of the rock that is deformed.

Microscopic fractures probably have a great effect when a fracture in a homogenous, isotropic rock is initiated. The stress on the rock that causes fracturing is concentrated and increases around the tip of the micro-fractures, which become linked to form visible fractures. Hydraulic fracturing can be another important factor in the occurrence of fractures. This takes place when a liquid (or gas) is placed under such great pressure that the rock's structural strength is exceeded. The liquid may have existed in the form of microscopic pockets or in closed fracture systems but can also be formed during the conversion of the mineral in the bedrock. The liquid can also have its origin in hot springs in the Earth's crust.

A number of geological situations can create conditions leading to cracks in the bedrock. Some of the most important are: 1) changes in stress due to movement in plates in the lithosphere (the Earth's outer layer); 2) changes in pressure from upper layers of bedrock due to erosion or deposits; 3) stress caused by changes in volume due to temperature fluctuations; 4) increased fluid pressure due to temperature fluctuations or other physical changes in the lithosphere.

Aside from geological factors, fractures can occur due to changes in stress caused by human activities such as mining, tunnel drilling or blasting.

6.3 Several definitions

The general term *fracture* usually refers to a brittle crack in the bedrock. A *fracture zone* is a series of fractures in close proximity to each other where "series" and "close" are relative terms that can vary widely depending on the frequency of the fractures in the surrounding bedrock. *Deformation zone* is a more general term which does not define the type of deformation that has taken place. Deformation in the zone can have been both plastic and /or brittle and in many cases may have occurred in different geological periods. The term *shear zone* defines a zone where shearing has taken place through soft, plastic deformation.

Micro-fractures are not visible to the naked eye but probably have a great impact on the mechanical characteristics of homogenous bedrock, both in terms of the occurrence of visible fractures (see above) and in terms of the transport of elements. Micro-fractures may have occurred when the bedrock was formed or during later geological events due to local variations in stress. This type of fracture has little large-scale impact since the physical characteristics of larger masses of bedrock (in terms of structural strength and transporting water/elements) are completely independent of existing planes of weakness (such as fractures, rock contact, deformation zones, etc). For this reason, international

research on nuclear waste disposal has concentrated on visible fractures.

Individual fractures can be divided into three main groups according to the way in which they were formed (see figure 6.1). These are:

- Extension fractures; the walls of the fracture have been pulled apart from the fracture plane formed, with minimal movement parallel to the fracture plane.
- Shear fractures; movement parallel to the fracture plane has occurred. This type of fracture is also called a fault.
- Compression fractures; filled, jagged fractures. The filling in the fracture consists of insoluble minerals made up of residual products caused when other more soluble materials were dissolved and transported away. This type of fracture is caused by a decrease in volume and normally occurs in sedimentary rocks.

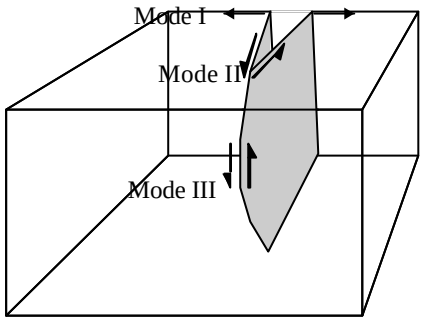

Figure 6.1: Sketch of the three main types of fractures based on the way in which they are formed (based on a figure in "Rock fractures and fluid flow", 1996)

In terms of structural geology and rock mechanics, fractures are usually described by beginning with the way in which the fracture spreads, i.e. the way in which the walls of the fracture move in relation to each other as shown in figure 6.1. Mode I

fractures are extension fractures and mode II or mode III fractures are shear fractures. Compression fractures (the walls of the fracture move toward each other) can be described as mode I, but in a negative direction. Most fractures cannot be described as purely mode I, II or III – they are usually a combination of all three types.

It is important to point out that fractures are often reactivated when new stress forms in the Earth's crust. Once a fracture has formed, it builds a plane of weakness in the bedrock in conjunction with continued and/or renewed deformation of the bedrock. This is the case regardless of whether or not there is any change in the stress field that caused the deformation. When the angle between the fracture plane and the main source of stress becomes too great during compression, the friction between the surfaces of the fracture prevents movement from taking place. This creates conditions under which new fractures can form.

Extension fractures

Extension fractures are often open or are filled with minerals and water. Plume-shaped structures often form on the clean surfaces of the fracture and occur when fracturing actually takes place. The fracture can form during one single event or it may be the result of a number of events.

Mineral deposits usually form from the walls of the fracture in towards its centre. It is not uncommon to be able to determine in greater detail the direction in which the walls of the fracture have moved in relation to each other and if mineral deposits have occurred in more than one stage, by examining a cross-section of the fracture.

Shear fractures

When shearing occurs, the walls of the fracture move laterally in relation to each other and a *"fault"* is formed. Even if a fault is

formed and spreads due to shearing, it is common for certain sections of a shear fracture to be exposed to compression forces while other sections are exposed to expansion forces. This is due to the fact that the plane of the fracture is uneven. Aside from this unevenness, the areas of a fracture surface exposed to these forces is determined by the way in which the bedrock on opposite sides of the fracture is displaced in relation to each other (figure 6.2). The term *fault* is normally only used in connection with noticeable relative movement and encompasses movement on more than one fracture plane.

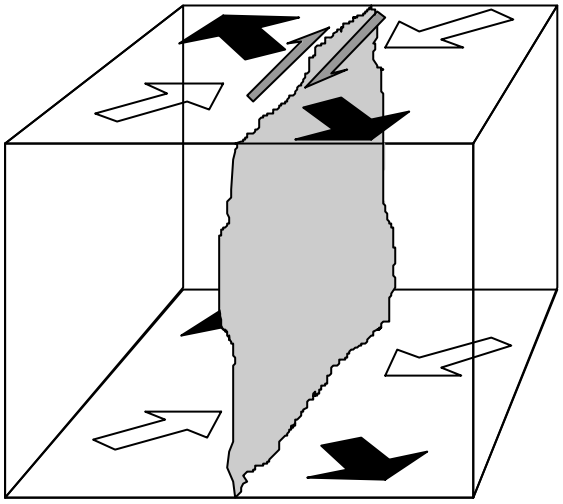

Figure 6.2: A shear fracture with clockwise rotation between the blocks can be caused by varying local stress patterns. The black and white arrows illustrate two main sources of local stress around a fracture, both of which could cause the same shear direction in the fracture. Friction between the fracture planes is, however, completely different in the two cases.

Faults are classified on the basis of the relative movement between bedrock on opposite sides and by the relation of the fault plane to the horizontal plane. Figure 6.3 illustrates several main types of faults that may occur.

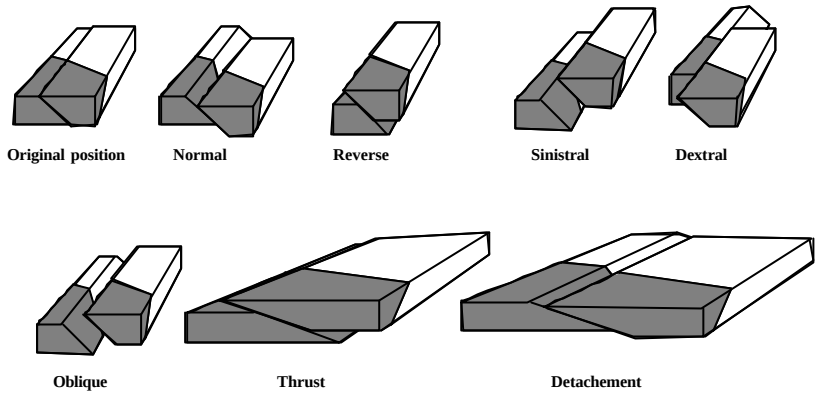

Figure 6.3: Main fault types.

How can the movement that has occurred in a fault be determined? On a larger scale, this is possible by fitting the "pieces" together on opposite sides of the fault to determine the relative direction and displacement. On a detailed level, there are often specific structures on the shear plane that may help determine the relative movement. This method normally only gives an indication of the most recent movement in reactivated faults.

6.4 Detecting fractures/fracture zones

The existence, position and extent of fractures and fracture zones can be determined through the use of remote analyses, geophysical measuring techniques, direct field observations, etc. These methods supplement each other and a certain method may be well suited for one category of fractures/fracture zones but be completely unsuitable for another. For example, the fractures that have been mapped through direct field observations are normally not seen at

all in conjunction with a remote analysis where larger scale zones or fractures (tens of metres and larger) can be identified instead.

Remote analysis/Photographic analysis

Remote analysis is an important tool at an early stage for identifying fracture patterns and larger fracture zones in an area. Satellite- or aerial photographs are used, as well as topographical maps and digital topographical databases.

Geophysical methods

There are a number of geophysical tools available to assist in evaluating the fracture systems in the intact bedrock in an area. Primarily, seismic, electronic or magnetic methods can be used from the ground surface. The development of radar in recent years has also made this useful for examining crystalline bedrock. One common feature of these methods is that they can only provide reasonably reliable indications of the state of a fracture zone. Individual fractures, particularly those lacking pore volume, are difficult to detect by these methods. The water-bearing properties, weathering and, to a certain extent, mineralogy, are often significant factors in determining whether or not fractures/fracture zones can be detected.

Field observations

Direct field observations on the ground surface, in tunnels and in boreholes/drill cores provide the best opportunity for a reliable, three-dimensional location and characterisation of fractures and fracture zones. Careful measurements of the orientation of fractures/fracture zones provide good conditions for correlating fractures between observation points. The character of a fracture/fracture zone, in terms of their geometry and mineralogy, can provide additional evidence for these correlations. The uncertainty of the observations increases with the distance between observation points. One limiting factor with surface

observations (aside from time and expense) can be a low exposure level. Fewer observations are taken under the ground surface for obvious reasons. The orientation and exact position of observations in boreholes are also limiting factors.

6.5 Fractures in time and space

With few exceptions, all rock-forming minerals are brittle in the physical environment on the surface of the Earth. The elastic characteristics of minerals, on the other hand, differ considerably (i.e. their capacity to withstand pressure using reversible deformation), which means that (minerals and) types of rock may have different fracture frequencies or fracture patterns even if they are exposed to the same deformation event. Therefore, no fractures may occur in some types of rock while deformation can occur in surrounding rock of a lower strength.

Since it was formed between 0.9 and 2 billion years ago, Swedish bedrock has been exposed to great variations in stress. At least four mountain chains have been formed and a large number of rift-related movements have taken place. The regional fracture pattern is surprisingly continuous and consistent over a great distance (hundreds of kilometres), even across important geological boundaries. This indicates that most of the regional fracture systems began after the formation of the mountain chains in the respective regions. The extensive fracture pattern varies a great deal, however, in terms of direction and frequency, between the northern and southern parts of the country.

6.6 Transport of water and elements

Water is transported in crystalline bedrock in fractures but only a small percentage of existing fractures is hydrologically active. Many fractures are more or less airtight or have a pore volume that does not come into contact with the flow of groundwater. Since the hydrogeological characteristics of fractures are very

heterogeneous, it has proven difficult to create realistic models of the flow of groundwater in bedrock.

Fractures with identical hydrological characteristics along the entire pore volume probably do not exist. Normally, the main volume of the groundwater flow is concentrated in channels or in one or more large fractures. The paths of the channels are complex and do not necessarily follow one specific fracture direction/group of fractures. The flow also varies in time and space depending on variations in water pressure and in the geometry, mineralogy, volume, etc of the channel. Water pressure in freely flowing groundwater changes constantly, partly due to the volume of water that is supplied through precipitation and infiltration from the upper layers of soil through contact between soil and bedrock and partly due to the amount of water that disappears from the system. Variations in "ebb and flow" also have an effect. Pressure gradients are normally small in ground water far under the surface, resulting in a limited flow of ground water. An earthquake can dramatically change this situation. Movements in the Earth's crust can suddenly change the geometry of a fracture in the bedrock and thereby also alter the flow of groundwater. Sudden events of this type do not only cause changes in pressure gradients – they also create new flow paths for the ground water. This can, in turn, lead to changes in the chemistry of the groundwater and of the mineralogy of the fractures affected.

A significant factor that affects water and the transport of various basic elements in fractures is the type and composition of the walls of the fracture, including possible fracture mineralogy. The elements are carried by the water primarily in the form of dissolved ions and to a certain extent, as suspended particles.

The speed at which ground water flows in a fracture varies from the centre out towards the walls of the fracture and is also dependent on the structure of the walls. The speed of the flow in turn affects the extent to which ions and particles are sorbed and accumulated on and in the walls of the fracture and to a certain extent, also in the host rock.

The sorption and diffusion of particles and elements in surrounding bedrock is normally not impeded by minerals in the

fracture or by other material on the walls of the fracture. If anything, diffusivity is higher in this type of material than in the host rock, partly due to the fact that porosity may be ten times higher. Sorption increases with the surface area available. It has been shown that basic elements and radioactive isotopes are sorbed in varying degrees. Therefore, the process ("chemical retardation") causes the speed of transport to be slower than might have been expected judging solely by the speed of the water's flow. Numerous studies have been made of the content of basic elements (including radioactive isotopes), on small samples on a laboratory scale and in different types of field tests with measurements taken under natural conditions. Problems can arise with the different testing methods. For example, if the content of an element is measured in the area surrounding a fracture, variations may be due to different processes and there may be no way of determining which one has been dominant. Therefore, the way in which basic elements react in a flow of groundwater in fractures, under varying conditions, is still far from clear.

6.7 A deep repository and fractures

Bedrock provides a natural barrier around a planned repository. How well this barrier functions depends on the bedrock's capacity to contain or transport radionuclides in the event of leakage, taking varying timespans into consideration.

Since noticeable changes in geological conditions usually occur very slowly, it is important to evaluate future scenarios based on the probability that they will occur. Possible geological scenarios that could occur in a timespan of 100,000 years include: earthquakes/tremors, aseismic neotectonism (i.e. movement of the Earth's crust near the surface without the actual occurrence of an earthquake) or the formation of inland ice. In all such cases, the strength of the bedrock and its reaction to changes in stress are of vital importance in determining how these events will affect the natural buffer around a planned repository. Changes in the bedrock in response to these possible scenarios can be modelled using

mathematical calculations based on geological models and measured parameters. Geological studies provide another more direct way of describing occurrences that have taken place during similar events in geological history. As an example, the date of movements in a deformation zone can be approximately determined. It is often found in such cases that large movements have occurred in the same zone on a number of occasions, despite the fact that the surrounding bedrock is more or less undisturbed.

Current stresses in the bedrock in Sweden cause low-magnitude seismic tremors each year. Movement between blocks of bedrock during these events is estimated to be less than 1 centimetre. The cause of the build-up of these stress forces is at issue, but the tremors occur at very different locations and certain areas are considered to be seismic or aseismic. Precisely locating the epicentre of an earthquake or tremor (exactly where the event took place in the Earth's crust) is difficult, but these events normally take place near fracture or deformation zones identified on the ground surface. It is therefore probable that the build-up of stress within a given area of the Earth's crust, during a certain period of time, is neutralised when a block of bedrock moves along an existing fault line.

On a large scale, the bedrock surrounding a planned repository should absorb and distribute future changes in stress without forming a new system of fractures. It has been established that a large number of the fractures and deformation zones found in the bedrock today are reactivated, i.e. movement has occurred in them on more than one occasion. The large systems of fractures and deformations zones today were formed hundreds of millions of years ago. The youngest section of bedrock of any consequence in Sweden was formed approximately 900 million years ago, in the form of "Bohus granite". This has a somewhat different system of fractures than the surrounding bedrock. This shows that regional stress, causing fractures in bedrock with *no* existing fractures (e.g. Bohus granite), can be absorbed by existing planes of weakness in another, previously fractured, section of bedrock. One difficulty lies in predicting the extent to which this *does not* occur. Generally speaking, the larger fracture systems are relatively continuous over

large areas and many fracture zones cross the boundaries between areas of differing geological ages.

Small-scale fracture systems around a planned repository determine the flow of ground water and the overall strength of the bedrock. All models of fracture systems (and of geology in general) on this scale are improved by access to as much input data as possible. The Swedish Nuclear Fuel and Waste Management Co's (SKB) final disposal model is based on the concept that a repository is constructed on a bedrock plinth with no appreciable fracture zones or heterogeneities, but is surrounded by planes of weakness that can absorb future movements in the Earth's crust. With the help of detailed local surveys of a possible site for a repository, a model of fracture systems and the flow of ground water can be created. Extensive research has been carried out in Sweden on water and element transport, particularly at the field laboratories at Stråssa, Stripa and Äspö. On behalf of the Swedish Nuclear Power Inspectorate (SKI), a hypothetical investigation to locate a suitable site for a deep repository (SITE 94) has been carried out. This investigation pointed to the need to integrate different types of field data in the areas of geology, hydrology, geochemistry and rock mechanics, to increase the reliability of the predictions made, based on the natural models created.

References

National Research Council, 1996: Rock fractures and fluid flow. National Academy Press.

Price, N.J. and Cosgrove, J.W., 1990: Analysis of Geological Structures. Cambridge University Press.

Ramsay, J.G. and Huber, M.I., 1987: Modern Structural Geology, volume 2: Folds and Fractures. Academic Press.

Scholtz, C.H., 1990: The mechanics of earthquakes and faulting. Cambridge University Press.

Reports from the Swedish Nuclear Power Inspectorate.

Reports from the Swedish Nuclear Fuel and Waste Management Co.

7 The effect of micro-organisms on a deep repository for spent nuclear fuel

Micro-organisms are by definition single-celled organisms that can only be seen with the help of a microscope, from where they get their name. The group includes bacteria but also encompasses single-celled animals and algae as well as yeast and mould fungi. Bacteria belong to the group single-celled prokaryote organisms, i.e. those lacking a well defined nucleus. The size of the bacteria varies greatly from several µm down to approximately 0.2 µm, depending on species and access to nutrients (1µm = 1/1000 mm). The micro-organisms that can live and procreate under the prevailing conditions in water-bearing fissures deep in the bedrock are primarily various species of bacteria. An example of this type of bacteria can be seen in figure 7.1.

7.1 Introduction

The fact that bacteria have a considerable impact on water chemistry in shallow systems such as the water in lakes or the ocean has been known for quite some time. The fact that dissolved oxygen in water is consumed during infiltration into the ground water in the soil and that this consumption is primarily a result of biogenic processes where organic material is broken down by micro-organisms to form carbon dioxide has also been known for a long time. But the fact that these bacteria exist in significant numbers in the ground water at great depth in crystalline bedrock is new knowledge that has come to light in the last 10-15 years. This

is partly due to the fact that new samples of deep ground water have become available. It is however, primarily in the research on the deep disposal of spent nuclear fuel that drilling and sampling in crystalline "granite" (i.e. bedrock that contains no mineral assets and is of no economic interest) have been carried out. The identification of biogenic processes at great depth in the bedrock has lead to a diffuse overlap in definition between what has traditionally been called the biosphere and the geo-sphere.

Internationally, Sweden is one of the forerunners in the investigation of deep biospheres (Karsten Pedersen and his group at the University of Gothenburg) but active research has also been carried out in Great Britain (Julie West and her colleagues at the British Geological Survey) and in Canada (Simcha Stroes-Gascoyne et al., AECL).

In the October 1997 issue of the magazine New Scientist, Julie West and Ian McKinley describe the results from research on canister and buffer stability in relation to bacterial activity. Their conclusions, based on laboratory studies and modelling, indicate that the bacterial activity that can be expected will probably have little effect on the service life of the canister. The calculations that have been made are based on the concept that is planned for Swiss and Canadian waste. West and McKinley also state that "Despite all of the efforts that have been made to understand how micro-organisms will behave in a waste repository, their actual impact has not yet been established".

The concept for storing high-level radioactive waste differs among countries with regard to the material used for the canister, the composition of the buffer, etc and the crystalline environment (Swedish bedrock) differs greatly in many respects from other geological environments (e.g. sedimentary bedrock or salt domes) in terms of the flow of water, water chemistry and access to organic material. Therefore, this summary of the scope of knowledge concentrates on Swedish conditions and more specifically on the material produced by Karsten Pedersen and his colleagues.

7.2 What do bacteria need to survive?

In order for bacteria to live and to be active they must have access to water, energy and, last but not least, carbon (organic or inorganic) for their structure. These are basic requirements that must be fulfilled. What then, is the environment like deep in the bedrock in terms of temperature, pH, hydrostatic pressure, the saline content of the ground water, etc? Bacteria can be found in many different environments. There are strains of bacteria that can withstand temperatures between -5° C and +110° C, pH values between 2 and 10 and saline contents up to 30% NaCl. Naturally, the most radically adapted bacteria are found in the most extreme environments and the flora of species varies widely. The hydrostatic pressure at a depth of 500 meters in the bedrock (the depth of the repository) is not expected to be of vital importance for the bacteria population. Radiation may have an impact on the bacteria flora, favouring the most resistant species.

Investigations also show that even if bacteria need water in order to survive, they prefer to be on a surface rather than in the water itself. This means that the number of bacteria found in ground water samples is lower than the number of bacteria on the walls of fissures.

Bacteria living in water-bearing fissures deep in the bedrock are anaerobic, which means that they live in an environment with no oxygen and use oxidants such as sulphates, trivalent iron and carbon dioxide instead of oxygen.

In a ground water environment at a depth of several hundred meters in crystalline bedrock, access to organic material is assumed to be a factor that limits the number of the bacteria. There are a number of indications that gases such as carbon dioxide, methane and hydrogen can be used by bacteria and that these gases can be found at great depths in the bedrock and have inorganic origins (figure 7.2). The extent of the bacterial activity and accessible amounts of the above-mentioned gases are the focus of current and planned research.

7.3 How can we sample and analyse the bacteria?

Access to boreholes is necessary in order to sample both the ground water and bacteria at great depth. Unfortunately, drilling and the existence of the borehole itself present a risk of contaminants entering the ground water. Therefore, it is essential, for example, to know what water is used for rinsing during drilling and what other types of tests (hydraulic measurements, checking the temperature, measurements etc) have been conducted in the borehole. It is also possible that the borehole itself connects water-bearing fissures in the bedrock so that water samples taken at a certain depth may not have come from that depth originally. A great deal of effort has been put into taking the best samples possible. Normally, water samples in deep boreholes are taken by closing off a section of the hole with rubber sleeves where a water-bearing fissure is known to exist, after which water is carefully pumped from the fissure up to the surface. It has often been questioned whether the bacteria in samples taken from great depths actually originate at that depth or whether the flow of water has been altered by other boreholes in the area. This is a difficult question but there are many indications of the existence of an active bacteria population at great depth. For example, bacteria-like fossils have been found in carbonate-coated fissures in crystalline bedrock at a depth of two hundred meters.

Since bacteria often form a carpet, known as a biofilm, on the surface of fissures, even solid samples can be of great value. These samples must be taken in such a way that they do not dry out.

In order to obtain results that are as valid as possible, it is of the utmost importance that the samples be kept under stable and natural conditions during transport from the site where they were taken, to the laboratory and that they are analysed as quickly as possible.

The analyses that are made provide information on the number of bacteria/ml in the case of water and the number of bacteria/g if solid samples have been taken. The different types of bacteria

contained in the sample, as well as the bacteria's level of activity, can also be measured. Since most samples contain several species of bacteria, it is not certain that all types are active or at least not equally active. Many of the species of bacteria found in deep ground water are unknown at this point but can nevertheless be placed in different families or groups with the help of DNA technology.

The number of bacteria/ml ground water that have been detected at the two sites in Sweden where the deep biosphere has been studied is between 103 and 106. The largest number of bacteria were found in samples taken from the uppermost 100 meters.

7.4 Which bacteria-related processes are of interest for a deep repository?

Two different situations can be identified. The first situation concerns the period during which the repository is in operation, i.e. when the tunnels are open, oxygen in the air can enter and the turnover of water in the bedrock is greatly affected by the open tunnels. Once the repository has been sealed, conditions are gradually expected to return to their original undisturbed state, i.e. an oxygen-free environment and a lower turnover of water than during the period when the tunnels were in use.

Most researchers agree that a large part of Sweden will be covered by glaciers within the coming 50,000 years. This will, of course, affect the deep biosphere. Research in recent years indicates that hydraulic pressure will increase greatly in places where the glaciers are not frozen completely to the bottom and that during certain glacial periods, oxygen-saturated water would reach a great depth relatively quickly. Organic production during these periods is expected to be very low and bacterial activity will consequently be reduced. Inorganic oxygen consumption will be dominant in these periods.

The processes that will dominate during the period when the tunnels are in use have been studied in the Äspö tunnel by Karsten Pedersen and his group at the University of Gothenburg. Since the ground water in bedrock normally has a reducing effect, a noticeable chemical gradient occurs in the interface where the ground water reaches the air in the tunnel. This interface is highly favourable for bacteria. Iron, manganese, sulphide and methane can be bacterially oxidised here while carbon dioxide is reduced and may convert to organic carbon. This provides conditions for the carpets of iron deposits that can often be seen on the walls of tunnels where ground water runs out of the bedrock. If the repository is open for a prolonged period, more of these deposits will have the chance to form.

One question that has been discussed is how long molecular oxygen will remain in the repository and in the tunnels after the repository has been sealed. This oxygen will be consumed in two ways: by bacterial activity or through the oxidation of e.g. divalent iron in the ground water and the mineral. Everyone seems to be in agreement that the oxygen will be efficiently consumed. How quickly this will occur however, is more difficult to prove but research is underway.

Can bacteria live in the bentonite buffer? The prevailing opinion is that they will at least have a very low level of activity and access to water seems be a limiting factor.

Can bacteria survive the temperature increase that is expected around a repository? Not all of them– and the bacteria flora will vary with the temperature but thermophilic bacteria can withstand the 60° - 80° C that is expected to be the maximum temperature in the immediate surroundings.

The processes that will be important in the long run after the repository is closed are related to the way in which bacterial activity affects the chemistry of the ground water as a whole, e.g. in terms of pH, the content of organic material, hydrogencarbonate content, etc.

A number of more specific areas can be expected to be of special interest.

a) Bacterial activity has a tangible effect on the water's hydrogencarbonate content. This is of great importance for the formation of complexes and possible transport of U and other actinides in the ground water. The same applies to the content of dissolved organic material (since bacteria can consume organic materials). Many radionuclides sorb strongly onto organic particles and in that way can be transported with the water if these particles are available.
b) The bacteria are active in redox processes, which are in turn of interest in determining the stability of the copper canister and the mobility of certain radionuclides in the event of leakage. In both cases, conditions leading to oxidation should be avoided. On the other hand, excessively high sulphide levels (caused e.g. by sulphate-reducing bacteria) should also be avoided to guarantee maximal stability of the copper canister. This makes sulphate-reducing bacteria and their activity interesting and studies at the Äspö Hard Rock Laboratory have been devoted especially to them (see below).
c) The possibility that radionuclides sorb directly on the bacteria and in this way become increasingly mobile has also been discussed but there are no indications at present that this would be of any particular importance. On the other hand, the carpets of iron deposits and microbes that are formed on tunnel walls in an open rock cavern have a great capacity to sorb radionuclides.

7.5 Sulphate-reducing bacteria – results from Äspö

Sulphate-reducing bacteria reduce sulphate to sulphide by oxidising organic material and producing carbon dioxide. Sulphide is a substance that causes copper to corrode. Determining the potential for sulphide production in the vicinity of the repository is therefore of great interest.

The sulphate-reducing bacteria seem to prefer a saline content of 6-8 g/l Cl for optimal activity as well as a supply of organic material and sulphate. Certain sulphate-reducing bacteria can utilise hydrogen gas as a reduction agent instead of organic carbon. Laboratory studies indicate, however, that sulphide production would be low in that case. To sum up, the results from Äspö provide the following data on the occurrence and activity of sulphate-reducing bacteria: The most favourable conditions for bacterial sulphate reduction are in the marine bottom sediment around Äspö where supplies of both organic material and sulphate can be found. The construction of the Äspö tunnel altered the flow of ground water so that the water was drawn into the fissures that were crossed by the tunnel, primarily where the tunnel is routed under the Baltic. The sulphate-reducing bacteria have in all probability adapted to the altered flow of water and their activity continues. A great deal of the sulphide formed is deposited as ferrous sulphate. The activities of the sulphate-reducing bacteria are much less apparent at depths below 200 meters where the tunnel is routed under land. Even though sulphate-reducing bacteria have been found in water samples taken from as deep as 600 meters, the results available indicate that their level of activity is relatively low or in other words, mass transport (the flow) is an important factor in the bacteria's level of activity.

7.6 Summary

The previously held opinion that bacteria only exist in the uppermost layers of the soil have been shown to be incorrect. Microbes exist deep in the Earth's crust. This provides conditions allowing them to interact in a greater number of geochemical processes than was previously known.

Only a few of the bacteria that have been identified at great depth are known species. This presents a strong argument for the fact that they do not originate at the surface through contamination caused by the drilling process. This does indicate that bacteria have

adapted to these special conditions and perhaps did so a long time ago.

The composition of the species varies greatly between boreholes located close to each other. This means that local conditions determine the composition, making it difficult to make predictions as to which of the species will dominate in the bedrock in a particular area.

Dissolved methane and hydrogen in very deep ground water serve as a source of energy for the ecosystem. This means that the ecosystem in very deep bedrock may be partially independent of the ecosystem at the Earth's surface.

The occurrence of molecular oxygen and sulphide at the level of the repository are important factors for corrosion of the canister and, in the event of leakage, also for the mobility of the radioactive elements. The occurrence of these elements is partially related to bacterial activity. Oxygen in the ground water is consumed under currently undisturbed conditions in the soil or at relatively shallow depth in the bedrock. This consumption is primarily bacterial but an inorganic buffer of divalent iron also exists, which is accessible in minerals. Oxygen in the air will come in contact with the canister, buffer and bedrock at a great depth while the repository is in operation. It is assumed that this oxygen will be consumed once the repository has been closed. Determining which processes will dominate and how quickly they will have an effect will hopefully be answered by the research that is currently underway.

On the other hand, the amount of bacterial oxygen consumption that can be expected when oxygenated ground water penetrates deeper into the bedrock during a glacial period is a more difficult question. The inorganic buffer may dominate under these conditions.

Two important bacterial processes that oxidise organic material in an anaerobic environment have been identified:

- The reduction of trivalent iron, which is found in hematite or iron oxide hydroxides on the walls of fissures.
- The reduction of sulphate and sulphur to sulphide through the action of sulphur–reducing bacteria.

A high sulphide content in the immediate vicinity of the canister increases corrosion and should therefore be avoided. However, the research findings now available indicate that the bacterial activity leading to the possible production of sulphide in the bentonite buffer will be very low due to limited access to water and a very limited flow.

Figure 7.1: The photo shows a sulphur bacteria from the genus *Thiothrix*. This filament-forming bacteria gets its energy by replacing oxygen with hydrogen sulphide while forming simple sulphur. The round "pearls" in the filaments is sulphur, which gives this organism its white colour.
Photo: Karsten Pedersen

Meddelande från översättaren: Jag har försökt ta orden/fraserna från vänster till höger och uppifrån och ner så långt som möjligt.

Oxygen in the environment
Carbon dioxide bond
Breathing oxygen
Monomers
Hydrolysis
Organic polymers
Bacteria (organic polymers)
Apatite in bedrock
Methane-forming organisms
Acetogenic bacteria
Oligomers and monomers
Acetum
Fermentation
Volatile sebacic acids and alcohols
Hydrogen bond
Chemotrophic carbon dioxide bond
Syntropic bacteria
Heterotrophic carbon dioxide bond
Sulphur-reducing bacteria
Iron-reducing bacteria
Manganese-reducing bacteria
Denitrifying bacteria
Several minerals in a fissure
Open repository
Iron, manganese and sulphur oxidising bacteria
Geothermally-formed gases
Depot with sedimentary organic material

8 Decommissioning nuclear installations

8.1 Introduction

Many countries have nuclear power plants that are no longer in operation or that will be taken out of operation in the near future. An uncertainty has been expressed from many sources as to the nuclear energy industry's capacity to decommission and dismantle these installations safely. International programmes have been started, e.g. OECD Nuclear Energy Agency's "Co-operative Programme on Decommissioning" to show that closed down installations can be decommissioned, dismantled and returned to "green field conditions" (the area can be used for any purpose after decommissioning) in a way that protects workers, the public and the environment against unacceptable effects of radiation and that this can be done at an acceptable cost [1].

KASAM's report, Nuclear Waste - the Scope of Knowledge 1987, contained a chapter on decommissioning nuclear installations. During the eleven years that have since passed, many nuclear power plants and nuclear fuel facilities have been decommissioned and in certain cases, dismantled. Experience from these projects has given us valuable knowledge in this area, which is of particular interest in the light of the Swedish parliament's decision in 1997 to shut down one nuclear reactor.

This chapter describes several of the decommissioning projects that are currently underway and the technology that is used in their implementation. An overview will be presented of the situation in

Sweden regarding preparedness for decommissioning nuclear power plants as well as legislation that applies in Sweden. Finally, a summary will be presented on current domestic and international discussions on the cost of decommissioning and release of material and sites for unrestricted re-use.

8.2 Background

As mentioned in KASAM's 1987 report, a nuclear power plant can be decommissioned in several stages. IAEA has defined three stages in the decommissioning process as follows:

Stage 1: "Safe shut down" with monitoring and periodic inspections

Stage 2: Isolate radioactivity in the smallest area possible. Less supervision and less frequent inspections than in stage 1.

Stage 3: All radioactive material (above the clearance limit) is removed. The area is released for unrestricted use ("green field conditions").

(See figure 8.1 which has been taken from reference [7]).

According to a report published by IAEA, "Nuclear Power in the World, April 1996" [2], there were 437 nuclear reactors in operation in December 1995. The report shows the ages of the reactors in a bar graph. Using the graph as a basis and assuming a 40-year operational period for each reactor, an initial approximation can be made on the need for reactor decommissioning as well as when this need can be expected to arise. The result is shown in table 8.1 below.

Table 8.1: Decommissioning rate for the world's power-producing reactors

Period (year)	**No. of reactors reaching the age of 40 - “retirement age”**
Before 2000	8
Between 2000-2010	30
Between 2010-2020	159
Between 2020-2030	211
Between 2030-2035	29

It should be noted that the table above deals with the shutting down of reactors, i.e. when the reactor can be expected to be taken out of operation after a period of 40 years. The actual dismantling of the facility may come at a later time, depending on a number of factors such as:

- The length of the period for "safe shut down" (which varies greatly in different countries),
- legislation and institutional factors,
- access to a repository for radioactive waste,
- aspects specific to the installation. For example, if the shut down reactor is at an installation where other reactors are still in operation, there may be common components whose operation could be hampered if the shut-down reactor were to be dismantled.

Figure 8.1: A schematic depiction of the three stages of decommissioning a nuclear power plant (including dismantling the buildings). From reference 7.

Intensive "Life extension" work on reactor installations is underway at numerous power plants in many countries. This work

could have a significant impact on the basic assumption of a 40-year operational period.

In addition to power-producing rectors, there were over 320 research reactors in operation in 1991 that are expected to be closed down sooner than the power-producing reactors. Most of them will be decommissioned by personnel from the research institute in question, relatively soon after closure.

Investigations and development work focused on the decommissioning of nuclear installations are being conducted nationally and by international organisations such as:

- the International Atomic Energy Agency (IAEA), Vienna
- the Commission of the European Union (EC), Brussels
- OECD Nuclear Energy Agency (OECD/NEA), Paris

IAEA's work is primarily directed toward formulating internationally accepted guidelines for various aspects of the decommissioning process and to compile a report on the scope of knowledge on the methods that are used. Examples of two technical reports being prepared are:

- Decommissioning nuclear installations that are not reactors
- Methods for minimising radioactive waste when cleaning and dismantling nuclear installations.

Between 1979 and 1994, EC has carried out three five-year programmes that support research and development work on dismantling methods in the member states. The programmes included partial financing of demonstration projects on reactors and a fuel reprocessing facility. Since the conclusion of the third five-year programme, EC-financed R&D projects have decreased noticeably and are limited to small projects such as gathering data on various dismantling methods, etc. This can be seen as a sign that the technology for dismantling nuclear power plants is now considered to be familiar and established.

OECD/NEA's Co-operative Programme on Decommissioning was started in 1985 to exchange experience and information on decommissioning projects that were underway. The programme's objective was to gather data that could subsequently be used to plan for the future industrial phase of decommissioning commercial nuclear power plants. After two five-year periods, the programme

agreement was renewed in 1995 for an additional five-year period. Through the Swedish Nuclear Fuel and Waste Management Company (SKB), Sweden has had a co-ordinating role in the programme since its inception.

The programme, which encompassed 10 projects in 1985, has 35 participating projects from 13 countries at present (1998). In addition to the exchange of information, the programme has established special working groups to study questions of primary importance that are of common interest to all participants. Decommissioning costs and recycling material from decommissioning are among the questions that are currently being analysed.

8.3 Current projects abroad

The projects in NEA's programme represent a broad selection of dismantling projects that encompass everything from experimental reactors to commercial reactors and reprocessing facilities from pilot plants to full-scale facilities. Table 8.2 shows a list of participating projects and provides a certain amount of information on decommissioning stages, costs, etc. It should be noted that the list only includes projects from the NEA programme. Decommissioning work is being carried out in many more projects in a great number of countries. Many other installations are being decommissioned in countries participating in the NEA programme, particularly laboratories and factories that were built in conjunction with the production of nuclear weapons.

Of the 35 projects in table 8.2, eight have been dismantled to stage 3 and their sites have been given clearance for unrestricted re-use, in other words, declared free of radiological restrictions. An additional 13 projects will be taken to stage 3. Four installations have been placed in varying degrees of "safe shut down" (stage 1 or 2). Work is being actively carried out in the remaining projects.

The planning and implementation of decommissioning work differs from country to country as well as from project to project in the same country. In addition to differences in the types of

installations, differences in organisational and financial factors as well as legislation can strongly influence the way in which decommissioning projects are planned and carried out.

The following is a short description of several projects that are cases in point.

Table 8.2: Projects in the OECD/NEA Co-operative Programme [Reference 1]

Facility	Type	Operation	Decom-missioning	Power or throughput	Project timescale	Cost estimate	Entry into Programme	Remarks
1. Eurochemic Reprocessing plant, Dessel, Belgium	Reprocessing of fuel	1966-74	Stage 3	300 kg/d	1989-2004	MBEF 5750 (1987)	1988	Execution by in-house staff
2. BR-3, Mol, Belgium	PWR	1962-87	Stage 3 (partial)	41 MWt	1989-2010	------	1988	EC pilot project
3. Gentilly-1, Canada	Heavy-water moderated/boiling light-water-cooled prototype	1967-82	Variant of Stage 1	250 MWe	1984-1986	MCAD 25 (1986)	1985	In dormancy
4. NPD, Canada	PHWR CANDU prototype	1967-87	Variant of Stage 1	25 MWe	1987-1988	MCAD 25.3	1988	In dormancy
5. Tunney's Pasture Facility, Ottawa, Canada	Isotope handling facility	1952-83	Stage 3	------	1990-1994	MCAD 13 (1991)	1990	Stage 3 achieved
6. 204 A/B Bays project, Canada	Storage & transfer pond	1947-94	Stage 1		1995-2003	MCAD 15 (1997)	1997	Part of the NRX Complex
7. Paldiski Decommissioning project, Estonia	Submarine reactors	1968-89 1983-89	Stage 1 Stage 1	70 MWt 90 MWt	1995-	------	1996	Ex-Soviet submarine Training Center
8. Rapsodie, Caderache, France	Experimental sodium-cooled fast-breeder reactor	1967-82	Stage 2	20 MWt	1983-1994	MFRF 131.7 (1989)	1985	In dormancy

Table 8.2 (Contd.): Projects in the OECD/NEA Co-operative Programme [Reference 1]

9. G2/G3, Marcoule, France	GCR, Electricity and nuclear materials production	1958-80	Stage 2	250 MWt each	1982-1993	MFRF 150 (1990)	1985	Stage 2 achieved
10. AT-1, La Hague, France	Pilot reprocessing plant for FBR	1969-79	Stage 3	2 kg/d	1982-1998	MFRF 220 (1989)	1985	Stage 3 achieved, EC pilot project
11. EL4, France	Gas-cooled/heavy-water-moderated	1966-85	Stage 2	70 MWe	1989-1999	MFRF 550 (1995)	1993	------
12. Building 211, Marcoule, France	Reprocessing workshop	1963-94	Stage 3	5 t/a	1995-2010	MFRF 1000 (1994)	1993	Including shut down operations
13. KKN, Niederaichbach, Germany	Gas-cooled/heavy-water-moderated	1972-74	Stage 3	106 MWe	-1995	MDEM 190	1985	Fixed-price contract, Stage 3 achieved
14. MZFR, Karsruhe, Germany	PHWR	1965-84	Stage 3	50 MWe	1984-2001	MDEM 370	1989	------
15. KWL, Lingen, Germany	BWR (with superheater)	1968-77	Stage 1	520 MWt	1985-1988	------	1985	In dormancy
16. Greifswald Decommissioning project, Germany	VVER	1973-90	Stage 3	8 x 440 MWe	------	------	1992	------

Table 8.2 (Contd.): Projects in the OECD/NEA Co-operative Programme [Reference 1]

17. HDR, Germany	BWR, nuclear superheater	1969-71	Stage 3	------	------	------	1993	------
18. WAK, Germany	Prototype reprocessing plant	1971-90	Stage 3	------	------	------	1993	------
19. AVR, Germany	Pebble bed HTGR	1967-88	Stage 1	15 MWe	------	------	1994	Stage 3 being planned
20. KNK Reactor, Germany	Sodium Cooled Fast Breeder	1971-91	Stage 3	58 MWt	1993-2003		1997	
21. Garigliano, Italy	BWR (dual cycle)	1964-78	Stage 1 for main containmen t	160 MWe	1985-1995	MITL 65 000	1985	------
22. JPDR, Tokai, Japan	BWR	1963-76	Stage 3	90 MWt	1986-1996	MJPY 22 500	1985	1981-1986 R & D, Stage 3 achieved
23. JRTF, Tokai, Japan	Reprocessing test facility	1968-70	Stage 3	------	1991-2004	MJPY 8 600	1991	------
24. KAERI Research Reactors, Republic of Korea	Triga Mark II & III	1962-95	Stage 3	250 kWt 2 MWt	1997-2000		1997	
25. Bohunice A 1 project, Slovak Republic	Gas-cooled, heavy-water-moderated	1972-79	Stage 1	150 MWe	-----	-----	1992	Decommis-sioning after fuel accident
26. Vandellos 1, Spain	GCR	1972-89	Stage 2	500 MWe	1992-2000	MESP 10 000	1993	------

Table 8.2 (Contd.): Projects in the OECD/NEA Co-operative Programme [Reference 1]

27. WAGR, Sellafield, United Kingdom	AGR	1962-81	Stage 3	100 MWt	1983-1998	MGBP 58	1985	EC Pilot project
28. BNFL, Co-precipitation Plant, Sellafield, United Kingdom	Production of mixed plutonium and UO_2 fuel	1969-76	Stage 3	50 kg/d	1986-1990	KGBP 2 245 (1990)	1987	Stage 3 achieved
29. BNFL B204 Primary Separation Plant, Sellafield, United Kingdom	Reprocessing facility	1952-73	Stage 2	Metal = 500 t/a oxide = 140 t/a	1990-2010	MGBP 90	1990	------
30. PFR, United Kingdom	Sodium Cooled Fast Breeder	1975-94	Stage 1	250 MWe 600 MWt	1994-2005		1997	
31. Shippingport, United States	PWR	1957-82	Stage 3	72 MWe	1985-1989	MUSD 91.3 (1990)	1985	Fixed-price contract, Stage 3 achieved
32. West Valley Demonstration Project, United States	Reprocessing plant for LWR fuel	1966-72	Stage 3	100 t/a	1982-2024	MUSD 1 400	1986	------
33. EBWR, United States	BWR	1956-67	Stage 3	100 MWt	1986-1996	MUSD 19.4	1990	------
34. Fort St Vrain, United States	HTGR	1976-89	Stage 3	330 MWe	1972-1995	MUSD 174	1993	Fixed-price contract
35. FEMP, United States	Hexaflouride reduction plant	1954-56	Stage 3	------	------	------	1993	------

Notes: 1. The decommissioning options are defined according to the IAEA Classification.

2. The cost data given in this table are not directly comparable owing to the fact that they refer to plants of different types, sizes and characteristics, to different decommissioning stages and to different time schedules for the execution of the projects.

Eurochemic reprocessing plant (Belgium)

Eurochemic was originally owned by a consortium of 13 countries but was gradually transferred to Belgian ownership after decommissioning in 1975. The site has been rebuilt into a central (nuclear) waste management plant and is also used as a central interim storage facility for reprocessed nuclear waste. The company, Belgoprocess, was established to handle all operations at the site, including decommissioning projects.
Several distinctive features of the project are:

- It is planned and implemented by in-house staff over a relatively long period of time.
- A pilot project was carried out on two small buildings to check methods and costs as well as to train personnel.
- Goal-oriented development work is underway in the area of technology to solve problems in the project. Significant progress has been made, such as:
  - *Decontaminating concrete surfaces*: A "shaving technique" has been developed using a diamond-tipped drill bit that provides an even surface (this simplifies measurements for clearance for unrestricted re-use) and leads to less secondary waste that is convenient for workers to handle.
  - *Decontaminating metal components* by dry blasting. Approximately 85% of all metal components are expected to be able to be made free of radioactivity to a clearance level.
  - *Ventilated breathing* masks and associated equipment have been developed for work in alpha-contaminated zones.

BR3 (Belgium)

BR3 was the first (West) European compressed-water reactor. The reactor was shut down in 1987. The decommissioning project has received support from EC's research funds. The project's first phase consisted of

- Chemical decontamination of the primary loop (removal of deposits containing radioactive material) to reduce the dose of radiation,
- A comparison of three different segmentation techniques on the thermal shield in the reactor pressure vessel.

The primary loop was decontaminated in April 1991. The method that was used was the Siemens CORD process that is applied in three stages. The radiation dose rate was reduced by a factor of 10 (average).

The three segmentation methods that were tested were

- mechanical methods (sawing),
- electrodischarge machining (EDM),
- Plasma cutting (in an underwater chamber).

Mechanical sawing proved to be preferable to the other methods due to the fact that less secondary waste was generated and the time factor was acceptable compared with the other methods.

Consequently, several types of mechanical sawing were used in the course of the project's second phase when the internal components of the reactor pressure vessel were lifted out and cut into segments to be placed in waste containers. During phase 2, a number of internal components that had been removed from the reactor pressure vessel 30 years ago were also cut into segments. This was done to gain experience in handling radioactive material after 30 years of "safe shut down".

The project is developing methods for decontaminating metal components to clearance levels. Both wet and dry blasting methods have been tested.

G2/G3 (France)

G2 and G3 were two gas-cooled, graphite-moderated reactors that were in operation between 1958 and 1980. The dismantling project has resulted in a stage 2 for the plant, with core components and other internal components encapsulated in the reactor pressure vessel of pre-stressed concrete. The external loops, including the steam generators, have been dismantled.

The main activity of the project was the removal of the external loops that consisted of 1500-2000 tonnes of carbon steel in each reactor. A melting plant (INFANTE) was built on-site to melt the contaminated material from the loops. A total of approximately 4600 tonnes were processed at INFANTE between April 1992 and June 1994 (material from other nuclear installations was also included in this amount). The ingots that resulted from this process are being stored pending a repository for very low-level waste or for a project for recycling material from the nuclear power industry.

The INFANTE plant itself is currently in the process of being dismantled. A new, larger melting plant is being constructed nearby.

AT-1 (France)

AT-1 was a pilot plant for reprocessing fuel from the breeder reactors, Rapsodie and Phénix. The plant was shut down in 1979. The decommissioning project, which is partially funded by EC, was started in 1982 and is expected to be completed in 1999.

The most interesting aspect of the project was the use of the remote-controlled dismantling machine ATENA for work performed in the high-level radioactive cells. ATENA was installed on the floor in the clean cells that were accessible and its 6 meter long jointed arm was extended by suitable manipulator machines to dismantle components in the otherwise inaccessible high-level radioactive cells. This work was carried out between 1990 and 1992 and was followed by the dismantling of storage cells, workshops, etc.

Final cleaning in the cells, including the decontamination of concrete surfaces, has been underway since 1995. It has been necessary to take drilling samples to determine how deeply the radioactive material has penetrated into the concrete.

KKN Niederaichbach (Germany)

The plant at KKN Niederaichbach was a 100 MW gas-cooled, heavy-water moderated reactor. It was commissioned in 1972, shut down in 1974 and was given "safe shut down" status (stage 1) in 1981. A permit to decommission to stage 3 was issued in 1987 after lengthy hearings and legal proceedings.

One main aspect of the project was the use of a specially designed, remote-controlled dismantling machine to remove the radioactive components in the reactor pressure vessel. This high-precision, rotary, masted machine, fitted with a manipulator, utilised a number of techniques to dismantle the vertically mounted internal parts in the pressure tube reactor. Some of the methods used were:

- polishing
- plasma cutting
- pipe cutter
- bolt removal
- vacuum cleaning

The remote-controlled dismantling and segmenting of KKN's core components took place between 1990-93. 522 tonnes of material were removed with a total radioactive content of 8.6×10^{12} Bq. The material has been packed into 139 waste containers which will be transported to the Konrad repository. Approximately 20% of the material that was removed contained less than 200 Bq/g. This part of the material has been sent to the melting plant Siempelkamp in Krefeld for recycling after melting, for use in the nuclear power industry (e.g. to produce waste containers).

The next step was the removal of the radioactive concrete, which took place between April – November 1993, after which all surfaces in the building were decontaminated and approximately 200,000 "clearance" measurements were taken. This was followed by control measurements taken by nuclear energy and environmental authorities. The plant was freed from the "nuclear energy act", the building was demolished and "green field" status was reached in July 1995. Figure 8.2 shows the KKN plant in operation and the memorial marking the site where the plant once stood.

An interesting feature of the KKN dismantling project is that it was carried out on a fixed-price contract with one main contractor.

MZFR (Germany)

MZFR was a 200 MWt heavy-water moderated pressure reactor in Karlsruhe that was in operation from 1965 to 1984. The plant is in the process of being decommissioned to stage 3, in several successive phases with a separate permit for each phase. Dismantling the plant will entail the removal of 72,000 tonnes of concrete and 7,200 tonnes of metal. Approximately 1,000 tonnes of concrete and 1680 tonnes of metal will be deposited as radioactive waste.

Dismantling has begun with the removal of the conventional sections of the facility. The turbine (150 tonnes) and the generator (130 tonnes) will be reused at other installations. The first five phases of the project have been completed. The secondary system has been dismantled and the primary loop has been decontaminated. The goal of the decontamination work was to ensure that as much of the contaminated material as possible was below 200 Bq/g, which is the current maximum limit that is allowed at the Siempelkamp melting plant. The material under this limit can be reused by the nuclear power industry.

A permit for the sixth phase was issued in April 1997. When phase 6 is completed, the reactor pressure vessel and its inner parts will be the only active components at the plant. Phase 7 will consist of segmenting and removing these components and the final phase of the project will entail decontaminating the area, clearance measurements and demolition of the buildings.

Greifswald (Germany)

There are eight Russian VVER pressurised water reactors at the Greifswald plant in north-eastern Germany (approximately 150 km south of the Swedish port of Trelleborg). In 1990, four of them had been in operation, one was about to be put into operation, one was ready to be started up and two were in the process of being built, when a decision was made to decommission and dismantle the entire plant.

The decommissioning project at Greifswald is probably the largest reactor decommissioning project in the world and is also important for other reasons, such as:

- This is a matter of decommissioning a nuclear power plant that has supplied 17,000 MW years of electricity through the years. The plant will be completely dismantled in such a way that the site can be used with no radiological restrictions.
- There are a number of similar reactors (VVER) in Russia and elsewhere that are soon to be decommissioned.
- A central concept of the project is to cut large components out of the reactor buildings. Once removed, the components will be moved to an interim storage facility where they will be kept pending further processing (decontamination and/or segmentation).
- The power plant was previously the largest employer in the area. The fact that both construction work and power production have been discontinued has caused a drastic reduction in number of employees. As a consequence, a decision has been made to use personnel from the plant to carry out the dismantling work as far as possible.

The interim storage facility is under construction for the fuel and components that are removed from the plant. One completed hall has already been put to use for interim storage of low-level (< 100 Bq/g) metal components from the plants.

At the time when the reactors were shut down, there was fuel in three of the reactors, in four fuel pools and in the central pool for fuel storage. According to the current permit, all of the fuel rods

are to be moved to dry storage in CASTOR vessels and these vessels will be placed in interim storage before June 2000. Moving the fuel rods to CASTOR vessels had high priority in the project.

JPDR (Japan)

Japan Power Demonstration Reactor (JPDR) was a 90 MWt boiling water reactor that was in operation between 1963 and 1976. The objectives of the dismantling project, begun in 1981, were to:

- gain first-hand experience of decommissioning work,
- develop/demonstrate suitable methods,
- gather data from the project on doses to personnel, waste, costs, etc.

The project began with a five year research and development programme on various techniques that were of interest and the preparation of a plan to dismantle the facility. The development work continued even after dismantling had begun in 1986 with large-scale tests of various techniques.

The JPDR project was characterised by the large number of techniques that were utilised and demonstrated in the various project activities. The reactor internals were sawn using plasma cutting. The pipe connections in the reactor pressure vessel were removed using explosive techniques or with a cutting wheel. An arc saw was used to cut the reactor pressure vessel into sections. The concrete biological shield was demolished by diamond sawing and drilling, water blasting with abrasives or by the use of explosives. A number of methods were used to decontaminate concrete surfaces.

JPDR was given stage 3 "green field" status during 1996. The data that were collected during the course of the project are now being analysed and utilised in an R&D programme for the future dismantling of commercial nuclear power plants.

WAGR Great Britain

Windscale Advanced Gas-cooled Reactor (WAGR) was a 100 MWt prototype reactor that was put into operation in 1962 and shut

down in 1981. The decommissioning project, partially funded by EC, is being conducted as a demonstration project for British reactors.

The high-level radioactive reactor internals are being removed by a remote-controlled, centrally positioned dismantling machine. At an early stage in the dismantling work a route for waste transport was established from the reactor pressure vessel to a specially built facility for waste packaging. This was done by raising two steam generators several meters. All 4 steam generators have now been lifted out of the vessel and transported to Drigg (approximately 40 km from WAGR) for final disposal by being cast in concrete.

The decommissioning project at WAGR has been greatly affected by financial and political decisions that were difficult to foresee at the project's inception. The government-run utility Central Electricity Generating Board withdrew from the project after two years, which led to a reduction in the annual budget. This forced the project to proceed at a slower pace, its timetable was extended and total costs increased as a result. The entire United Kingdom Atomic Energy Authority (UKAEA), WAGR's owner, was later reorganised. A large division of the company, AEA-Technology, was divested, privatised and is now listed on the stock exchange.

Fort St. Vrain (USA)

Fort St. Vrain is a plant in Colorado that was a 330 MWe high-temperature gas-cooled reactor and was the only one of its kind that was ever put into commercial operation. It supplied electricity to the grid between 1976 and 1989. The plant's owner, the Public Service Company of Colorado, decided to totally decommision the plant to stage 3 after a study that compared immediate decommissioning with "safe storage" for 55-60 years.

The fuel was moved to a temporary, specially built, dry storage facility on site, after which the decommissioning project began in July 1992. Some of the most interesting aspects of the decommissioning project are:

- Fixed price contract based on tenders,
- Diamond wire sawing was used to remove and segment the cover on the reactor pressure vessel, which was made of reinforced concrete,
- All penetrations in the reactor pressure vessel were sealed and the vessel was filled with water (unique for a gas-cooled reactor project). The internals were segmented under water,
- Very short dismantling period (39 months),
- Good relations with the public thanks to very good communications with the municipality and with state and federal authorities as well as with the media.
  A gas-fired power plant has been built on the site.

Other projects

At present, NEA's programme includes 35 projects. Some of most characteristic aspects of 10 of these projects have been briefly described above. The projects described have been chosen to illustrate ways in which circumstances and problems can vary from project to project. Projects not described here each have particular aspects that have affected their execution.

8.4 The situation in Sweden

As is apparent from the information above, no Swedish projects are involved in the NEA programme. However, compared with many other countries, Sweden has a high level of preparedness in terms of infrastructure, technical know-how and funds allocated for decommissioning nuclear power plants. The following should be noted:

- Sweden has had a well-functioning repository for low- and medium-level radioactive waste (SFR) for many years. However, SFR is only licensed to accept operational waste.
- Sweden also has an interim storage facility for spent nuclear fuel (CLAB) which means that fuel from a shut down reactor can be transported away from the plant with no appreciable delays.
- In addition, there is also a well-tested transport system for moving fuel and waste by sea from the nuclear power plants to CLAB or SFR.
- Experience from decommissioning projects and of the techniques used to perform this work has been gathered by
  - decommissioning the research reactor R1 in Stockholm and the experimental plant in Studsvik
  - replacing steam generators at Ringhals
  - the FENIX project at Oskarshamn (renovating the Oskarshamn 1 reactor) and other larger modernisation projects.
- The co-ordinating function of the NEA programme has made it possible to stay up-to-date with the technical advances made abroad.
- It is estimated that by 2010, there will be sufficient funds in the Nuclear Waste Fund to cover the expenses for decommissioning the nuclear power plants and for managing fuel and other radioactive waste.
- Swedish authorities have also planned ahead for the decommissioning of nuclear power plants. The Swedish Radiation Protection Institute has presented preliminary deliberations and standpoints in regard to decommissioning nuclear installations [3].

To supplement the description of the level of preparedness given above, an account of the legislation for decommissioning nuclear installations in Sweden will be presented, as well as a comparison of decommissioning costs in Sweden, Germany and in the USA.

Legislation

The main laws governing the decommissioning of nuclear power plants in Sweden are

- the Act on Nuclear Activities (1984:3) which places responsibility on the licensees for
  - managing and disposing of operational nuclear waste safely,
  - decommissioning the installations safely when they have been taken out of operation.
- the Radiation Protection Act (1988:220) requires that anyone who has carried out operations involving radiation is responsible for ensuring that the radioactive waste resulting from these operations is managed and, when necessary, disposed of in a satisfactory manner in terms of radiation protection.
- the Act on the Financing of Future Expenses for Spent Nuclear Fuel etc (1992:1537), which requires the licensees to make yearly reports to the Swedish Nuclear Power Inspectorate (SKI) estimating costs for all measures for managing spent nuclear fuel and radioactive waste as well as for decommissioning nuclear power plants.
- The Act on the Phasing out of Nuclear Power (1997:1320).

In addition, most of the regulations that apply while the facility is in operation will also be applicable during the decommissioning stages. This includes legislation on dose limits and health physics for work involving ionising radiation, regulations limiting the release of radioactive substances, etc. SKI's general regulations, which take effect in 1999, also cover the operational stage of a phase-out – shutdown operation – as well as storing and handling spent nuclear fuel and nuclear waste including the decommissioning stage itself. SKI is considering whether a special regulation for phase-out/decommissioning is necessary (e.g. pertaining to all steps in the chain – planning, dismantling, treatment/handling, final disposal, etc). SKI can set conditions for an individual installation (e.g. Barsebäck 1) if this is deemed necessary for reasons of safety.

Cost estimates for decommissioning

The costs for dismantling nuclear power plants have been discussed for many years, both nationally and internationally. In 1989, a special group was established in the NEA programme to identify possible causes for the large differences in costs that were reported for the various projects in the programme.

Great discrepancies were also noted by SKI between the estimates made by the Swedish Nuclear Fuel and Waste Management Co (SKB) for decommissioning Swedish nuclear power plants and the estimates made abroad for decommissioning the same types of facilities. A consultant was brought in to compare the Swedish estimates with those made for German and American facilities.

The results of the two studies are summarised in the following paragraphs.

The NEA programme's Task Group on Decommissioning Costs [4]

Costs for 12 projects were compared. A cost matrix was prepared in order to make direct comparisons to as great an extent as possible, with an itemised division of cost groups into items and including the period when the costs were incurred. In addition, each item was placed under one of the following headings: labour, capital expenses and miscellaneous.

The data gathered had to be refined and adapted several times in a dialogue between the Task Group and project managers in order to be able to make comparisons. The two most important lessons learned from the task group's work were

- that it is very difficult to make direct comparisons between cost estimates made in different countries. The figures submitted can be misinterpreted and misused without careful definitions of the content of the cost items;
- that there were no internationally standardised lists of cost items or methodology for cost estimates of decommissioning projects.

The second point mentioned above is now in the process of being rectified. Co-operation has been established in the NEA programme's task group to establish a uniform, standardised list of

cost items and definitions between the programme's task group – the International Atomic Energy Agency (IAEA) – and the European Commission (EC). It is very advantageous to co-ordinate this work with the ongoing work in the USA with "Hazardous, Toxic and Radioactive Waste Remedial Action" under the auspices of the Department of Energy, the Defence Department and the Environmental Protection Agency.

A comparison between Swedish and foreign cost estimates

The difficulty in making direct cost estimates between dismantling projects was clearly demonstrated when the estimates made by SKB for dismantling the 12 Swedish power-producing reactors were compared with similar estimates made by utilities in Germany and in the USA. When the direct comparison showed the Swedish estimates to be significantly lower than the foreign ones, the Swiss company NAC International was called in by SKI to investigate the causes of the discrepancy. NAC International presented its analysis in two reports to SKI [5,6].

Table 8.3 shows the nominal differences in estimates, after a certain ”normalisation” to enable a meaningful cost comparison.

Table 8.3: Reference reactors and normalised cost estimates [6]

Country	Reactor	Type	Output MW	Startup	Costs * MSEK
Sweden	Oskarshamn 3	BWR	1160	1985	1258
	Ringhals 2	PWR	875	1975	902
Germany	Brunsbüttel	BWR	770	1975	3225
	Biblis A	PWR	1146	1977	2631

USA	WNP-2 Trojan	BWR PWR	1095 1095	1984 1976	1763 1425

* Estimated on the basis of the exchange rate as of Jan. 1, 1994:
1 DEM = 4.8 SEK 1 USD = 8.3 SEK

NAC International's analysis shows that

- The time and manpower required for some of the main activities such as shutdown operation and decommissioning vary by up to a factor of 4 among the countries. This can be explained by institutional or infrastructural reasons such as
  - A limit on the size of waste packages sent to the German repository means that components must be cut into much smaller sections than in Sweden, where ISO-standard containers are used for transport and final disposal.
  - The lack of a facility in the USA similar to CLAB, which can accept spent fuel for interim storage, means that each licensee must find a way to manage its own reactor fuel. It also means that for as long as there is fuel in the reactor plant, an almost complete operational organisation must be maintained.
- Access to an efficient operating waste management system, including both transport and final disposal, gives Sweden a significant advantage in terms of costs.

To summarise, NAC International offers the following explanations for apparently large differences in costs in table 8.3:

Germany/Sweden

The differences of **MSEK 1967** for BWR and **MSEK 1729** for PWR comprise:

	BWR	**PWR**
Higher wages/more man hours	59 %	57 %
Waste treatment/final disposal	28 %	22 %

Insurance	3 %	4 %
	90 %	83 %

The remaining difference can be explained by the fact that the exchange rate for the Swedish krona was somewhat undervalued.

USA/Sweden

Table 8.3 shows higher costs in the USA – a difference of **MSEK 505** for BWR and **MSEK 523** for PWR.

The USA shows higher wage costs but fewer man hours than Sweden with an overall lower wage cost for decommissioning. This advantage is more than offset by the items: dismantling buildings, waste management and insurance. In total, these items can explain 69% of the BWR difference and 63% for PWR. Adjustments in the exchange rate could explain almost the entire remaining difference for BWR and all but 10% of the difference for PWR.

8.5 Decommissioning waste and clearance

Radioactivity in material that has arisen from operations under radiological control by an authority can be released for unrestricted use if they meet certain clearance criteria. The international criteria for clearance are: the individual dose is less than 10µSv/year and that the collective dose is less than 1 manSv/year's operation or that protection has been shown to be optimised.

If conditions for the use of the material must be set for reasons of radiation protection, clearance is no longer valid. In this case, the material may be used under the supervision of an authority (with dose limits and optimisation).

The costs for managing the large amounts of contaminated material generated when a nuclear power plant is dismantled make up a significant portion (up to 25%) of the total costs of such projects. Consequently, reducing the amount of material that must be disposed of as radioactive waste has been given high priority by project managers. Recycling the material (or its direct reuse or deposit) for use without radiological restrictions is one way to achieve this goal. Furthermore, recycling, particularly metals, contributes to the conservation of the world's resources as well as to environmental protection. However, the existing criteria for clearance of recyclable material are applied differently in different countries, which limits the potential for recycling.

Discussions on clearance for recycling are underway primarily within the

- International Commission on Radiation Protection (ICRP), which has drawn up the basic principles for protection against ionised radiation [8].
- International Atomic Energy Agency (IAEA), which has attempted to convert the general principles into recommendations for nuclide-specific clearance levels.
- European Commission (EC), which is formulating recommendations of its own for member states.
- NEA programme's Task Group on Recycling and Reuse, which can be considered to be representatives for the future users of the recommendations and criteria that IAEA and EC are in the process of formulating. The NEA programme's group has studied recycling as a whole, including today's practices, suitable technologies and have analysed internationally proposed recommendations and criteria for clearance [12].

A number of expressions are used to define certain specific events and conditions in conjunction with the work and discussions in this area.

One type of exception – **exclusion** – applies to sources of radiation that cannot be regulated through legislation, e.g. K-40 in the human body, cosmic radiation at ground level, etc.

Another type of exception – **exemption** – was previously used to describe all radioactive material outside of regulatory control, i.e.

both material that is completely exempted from control and also that which has first been regulated and later cleared for unrestricted re-use. In recent times, the expression has been limited to apply only to radioactive material that has never been put under regulatory control.

Clearance applies to material that has been removed from regulatory control.

In 1988, the IAEA and NEA published a joint document – Safety Series 89 [9] to direct policy for "exemption" and "clearance". It was proposed that the public should not be exposed to more than **10 µSv/year/activity** ("practice") (the equivalent of a lifetime risk of cancer fatality of 5×10^{-7}). Based on this proposal, both the IAEA and EC have issued recommended nuclide-specific levels of concentration for clearance [10,11].

In addition to these documents, the IAEA and EC have each published their own "Basic Safety Standards" [14,15] regarding protection against ionising radiation. Both documents provide lists of nuclide-specific exemption levels. Exemption levels are 10 times higher than clearance levels for nuclides that are of interest to the nuclear energy industry (low-level waste).

In their recommendations, both the IAEA and EC have only taken radiological risks in conjunction with clearance into consideration. NEA's Task Group has tried to see recycling in a broader perspective and has included both radiological and non-radiological risks in its analysis. The group compared recycling 50,000 tonnes scrapped steel utilised so that the maximum individual dose was limited to 10 µSv/year with depositing this amount as radioactive waste and with producing the same amount of new steel in the USA. The results are shown in table 8.4 and indicate that

- the radiological risks in conjunction with both alternatives are very small compared with the non-radiological ones,
- the non-radiological risks are much lower in the case of recycling because the manufacturing process begins with scrap. The main risk that is avoided is mining the iron ore.

Radiation protection and managing radioactive material has up until now primarily pertained to artificial nuclides that arise in the

nuclear fuel cycle (Nuclear Industry, NI). In recent years, awareness has increased about naturally occurring radioactive material (NORM) and its increased concentrations in many industries outside of the nuclear fuel cycle (Non-nuclear Industries, NNI).

This technologically concentrated NORM in NNI has the same level of radioactivity as low-level nuclear waste and is comparable with candidate material for exemption and clearance in NI but occurs in much greater quantities.

Laws regulating this type of NORM are being drafted in the USA and Europe. In the USA, a concept has been presented for "Suggested State Regulations on Naturally Occurring Radioactive Material (NORM)". As was previously mentioned, EC issued a directive in May 1996 with revised safety norms (Basic Safety Standards) pertaining to radiation protection for workers and the public. The directive covers radioactivity in both NI and NNI and must be ratified by EU member states within 4 years (before May 2000) [15].

Table 8.4: Summary of the health risks of different ways of managing radioactive scrap metal.

Impact categories	**Recycle/reuse**	**Dispose and replace**
*Radiological risk**	• 10^{-7} to 10^{-6} fatal cancer risk to metal workers and public • 10^{-2} to 10^{-1} population risk per year of practice	• Potential elevated cancer risk to miners
Non-radiological risks		
• Accidents (workplace)	• About 7 fatalities or serious injuries to workers	• About 14 fatalities or serious injuries to workers
• Accidents	• 10^{-2} fatality risk to	• 10^{-2} fatality risk to

(transportation) • Chemical exposure from smelting ** • Chemical exposure from coke production	workers and public • 10^{-3} fatal cancer risk to workers; 10^{-4} to public • None	workers and public • 10^{-3} fatal cancer risk to workers; 10^{-4} to public • 1 fatal cancer risk to workers; 10^{-2} to public

* Risk estimates represent maximum individual lifetime risk associated with a 50 000-t throughput, operated so that individual dose does not exceed 10 µSv/a.

** Maximum individual lifetime risk of cancer fatality resulting from one year of exposure at the maximum permissible concentration in the United States.

It is important for the public's understanding that all radioactivity must be regulated in a perceivably consistent way. In the newly published regulations from the US Nuclear Regulatory Commission for clearance of sites of nuclear power plants, a criteria of 250 µSv/year has been specified as the average dose to members of the critical group among the general public (cf. 10 µSv/year in Safety Series 89). The individual dose level of 250 µSv/year is also proposed in a draft for regulations pertaining to NORM waste in the USA.

EC's Basic Safety Standards divide the industries that handle radioactivity into two categories:

– "practices" where radionuclides are handled with consideration to their radioactive, fissile or fertile characteristics.
– "work activities" where naturally occurring radioactivity is concentrated in production systems, products, by-products or waste.

As an example, it should be noted that "practices" pertain to NI and "work activities" pertain to NNI such as the phosphate and petroleum industries.

The current regulation of NORM material is quite inconsistent compared with the regulations for managing similar material in NI as is illustrated below:

– The general clearance limits for specific activities in Sweden for material from the nuclear energy industry is 500 Bq/kg for beta and gamma emitters and 100 Bq/kg for alpha emitters (i.e. 0.5 and 0.1 Bq/g).

According to EC's current directive 84/467 Euratom (1984)[1], radioactivity with concentrations under 100 Bq/g or 500 Bq/g for "solid natural material" are exempted from regulatory control. The directive is also interpreted differently from country to country:

- In Holland, the 100Bq/g level is used for exempting waste from the petroleum or gas industries. Oxide scales from pipes on drilling platforms, with levels of radioactivity under this level, are handled as chemical waste instead of as radioactive waste.
- On the other hand, Germany uses the 500Bq/g level for the same type of material [13].

– On off-shore facilities from many countries, these oxide scales (with specific radioactivity of several hundred Bq/g) are ground into powder, mixed with water and pumped into the sea [13].
– Concrete from the dismantling of the MZFR nuclear power plant in Karlsruhe, Germany was used as filling material for road construction in Karlsruhe. The clearance level was 0.5 Bq/g for beta-gamma and 0.05 Bq/g for alpha emitters [1]. A permit was recently issued to a company in northern Germany to use slag products from smelting scrap from the petroleum/gas

[1] EC directive 84/467 still applies but will be superseded by directive 96/29/Euratom (often referred to as BSS, Basic Safety Standard), which was adopted by the Council on May 13, 1996. The member states have four years from this date to implement the directive in national regulations. The new directive, which in reality is referred to by nearly everyone, has nuclide-specific "exemption levels" which supersede the levels stated here.

industries for the same purpose – as backfill for road construction. The clearance level in this case was 65 Bq/g (Ra 226). It was necessary to dilute the material by a factor of 4, which resulted in an actual clearance level of just over 16 Bq/g [13].

The difference in clearance levels for radioactivity from the two different sources is very difficult to explain in terms of radiation protection since the material in both cases is used for the same purpose.

– Exemption levels in the EC directive only apply to radioactivity within NI. There is no equivalent list for "work activities" (NNI). However, certain reports issued by EC contain statements that seem to suggest that an inconsistent double standard and other criteria might apply for exemption/clearance of material from NNI, for example:
  - "The same radiological criteria as for exemption (in NI) cannot be applied" [16].
  - "The concept of triviality of individual doses does not seem to be relevant" [16].(The concept of triviality is the cornerstone of Safety Series 89,s 10µSv/a)
  - "Table A of Annex 1 (EC BSS) .... is not meant to apply to natural radioactive substances arising in bulk from oil and gas production".

These opinions were reflected in presentations and discussions that took place in a meeting in Amsterdam in September 1997 on radioactivity in NNI.

The question of whether the same or different criteria should apply for exemption/clearance of material from NI and NNI has not yet been decided. From the viewpoint of radiation protection, it will be very difficult to justify different criteria. The difference is due to the fact that many countries and organisations use individual dose criteria – 10 µSv per year from which the clearance levels are derived. Varying clearance levels may be arrived at (Bq/g), depending on the conditions in the country (e.g. the way in which the material is used and the volumes in question). It is of course desirable to establish clearance levels that are acceptable to as many countries as possible, particularly for material transported

between countries (e.g. scrap). Acceptance by e.g. the public must also be taken into account in discussions of this type.

8.6 Summary

Nuclear power plants are being decommissioned in a number of countries. Projects carried out within the OECD/Nuclear Energy Agency's programme have shown that it is technically feasible to dismantle nuclear power plants and to remove all artificial radioactivity from the site. It has also been demonstrated that this can be done in such a way that workers, the public and the environment are protected against unacceptable effects of radiation.

Sweden is particularly well prepared for dismantling nuclear power plants in terms technical know-how, allocated funds and an infrastructure for managing the resulting decommissioning waste. These preparations also include authorities and agencies that have initiated processes for necessary deliberations and decisions. After closer scrutiny, the relatively low costs that have been estimated in Sweden compared with a number of other countries are to a great extent due to the infrastructure that is already in place and to other institutional factors.

Recycling of contaminated material resulting from the dismantling of nuclear installations can significantly reduce decommissioning costs. Clearance levels for radioactive material and other criteria making recycling possible are being discussed in many international organisations. In recent years, these discussions have also included radioactive material from "non-nuclear" industries where, due to technological factors, naturally occurring radioactivity becomes concentrated to approximately the same level as is found in low-level nuclear waste, but in much larger volumes.

References

The NEA Co-operative Programme on Decommissioning
The First Ten Years 1985-1995
OECD Nuclear Energy Agency, Paris, 1996.

Nuclear Power Reactors in the World, April 1996
Reference Data Series No. 2
International Atomic Energy Agency, April 1996.

Strålskyddsöverväganden i samband med avveckling av kärntekniska anläggningar.
Swedish Radiation Protection Institute
Huvudenheten för kärnenergitillsyn.
6 February 1996.

OECD/NEA Co-operative Programme on Decommissioning
Report from the Task Group on Decommissioning Costs
CPD/DOC(21)4 June 1991
Comparisons of Cost Estimates of Nuclear Power Reactor Decommissioning in Sweden, Germany and the United States, Revision 1.
NAC International, Zurich September 1995

Selected Detailed Analysis of Swedish and German Decommissioning Estimates, Final Report.
NAC International, Zurich September 1995

PAUL R
Comparison of the Methodology of Decommissioning
Cost Estimations in Sweden and Germany
SKB Arbetsrapport 95-25 March 1995

1990 Recommendations of the International Commission on Radiological Protection. ICRP 60 Pergamon Press 1991

INTERNATIONAL ATOMIC ENERGY AGENCY
Principles for the Exemption of Radiation Sources and Practices from Regulatory Control.

IAEA Safety Series No 89, Vienna 1988

INTERNATIONAL ATOMIC ENERGY AGENCY
Clearance Levels for Radionuclides in Solid Materials
Interim Report for Comment
IAEA TECDOC-855 January 1996

Recommended Radiological Protection Criteria for the Recycling of Metals from the Dismantling of Nuclear Installations.
European Commission Draft February 1995

OECD NUCLEAR ENERGY AGENCY
Nuclear Decommissioning
Recycling and Reuse of Scrap Metals
OECD 1996

VAN VEERS A W et al
Current Practices of Dealing with Natural Radioactivity from Oil and Gas Production in EU Member States.
Nuclear Science and Technology.
European Commission EUR 17621 EN 1997

International Basic Safety Standards for Protection against Ionising Radiation and the Safety of Radiation Sources.
IAEA, FAO, ILO, OECD/NEA, WHO and PAHO, 1994

EUROPEAN COMMISSION
Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of workers and the general public against the dangers arising from ionising radiation.

MARTIN A et al
Materials containing natural radionuclides in enhanced concentrations.
Nuclear Science and Technology.
European Commission EUR 17625 EN 1997

9 International overview

Generally speaking, the nuclear waste programmes in many countries have passed the stage of accumulating a broad base of knowledge and developing methods. For the most part, methods have been selected for managing and disposing of spent nuclear fuel and nuclear waste. Applied research and development, e.g. in underground hard rock laboratories, is now under way. In few countries, this is being done in tandem with programmes to find a suitable site for a deep repository. As these programmes enter the execution phase, technical and scientific developments in, e.g. the area of transmutation, are also being monitored. The programmes have encountered difficulties in certain countries due to a lack of public support.

This chapter will present a brief summary of the most recent developments in several countries of particular interest: Finland, Great Britain, France and Canada. The description will be limited to spent nuclear fuel and high level radioactive waste with the exception of Great Britain, where the siting process for a repository for intermediate level, long-lived waste has recently been stopped after a public hearing.

9.1 Finland

Spent fuel was previously exported from the Lovisa nuclear power plant to Russia for reprocessing. Finland's Act on Nuclear Activities now prohibits the export or import of nuclear waste. The fuel from both the Finnish nuclear power plants in Lovisa and in Olkiluoto is expected to be placed in a common repository. As is the case in Sweden, the Finnish power utilities have formed a

special company, Posiva Oy, which is responsible for managing nuclear waste.

As in Sweden, the producer of the waste, i.e. the nuclear power utilities, is responsible for the treatment and final disposal of this waste. The Ministry of Trade and Industry has the overall responsibility for supervision, while the Radiation and Nuclear Safety Authority (STUK) monitors safety, issues regulations and makes statements regarding safety. The power utilities are responsible for all expenses connected with final disposal. Funds are allocated on a continuing basis in a nuclear waste fund that is administered by the Ministry. In current monetary values, the costs for final disposal are estimated at 3.8 million Finnish marks.

The technical plans are also quite similar to those in Sweden. The spent fuel will be enclosed in a canister with an iron core, surrounded by a 5 cm thick copper cylinder. The canisters will be deposited at a depth of 400-700 meters underground and will be surrounded by a protective layer of bentonite clay.

The siting process in Finland began with an extensive survey of the bedrock, resulting in a large number of prospective areas for a repository. The site investigations have now been concentrated to four sites:

- Olkiluoto on the Gulf of Bothnia
- Romuvaara in Kuhmo in eastern Finland, near the Russian border
- Lovisa on the Gulf of Finland
- Kivetty in Äänekoski in central Finland

Two of the prospective sites, Olkiluoto and Lovisa are located near both of the nuclear power plants. Posiva Oy has established local offices in the communities that are located closest to the four potential sites for the repository, where it is conducting information and contact activities.

According to a previous decision by the Minister on the siting investigations, a site for a repository must be selected by the end of the year 2000 and final disposal must begin by 2020. The Minister’s decision in principle, which must be ratified by the Parliament, is necessary for the repository. The following is required to make a decision in principle:

- siting acceptance by the municipal council (veto right)
- preliminary evaluation by STUK of the installation's safety
- an environmental impact statement

The Finnish programme has consequently now taken shape to the extent that there are four candidate sites for a repository and a final decision will be made during 2000. In this regard, Finland's Ministry of the Environment has sent a letter to the Swedish authorities describing these plans. This letter is based on article 3 of the convention on environmental impact assessment in transboundary contexts which was produced by the UN Economic Commission for Europe, ECE, the so-called Espoo Convention. In the letter, the Finnish Ministry requests information from the Swedish National Environment Protection Board, the Swedish authority responsible for such matters, as to whether any Swedish regulatory authorities and/or citizens intend to participate in the environmental impact statement evaluation and to state an opinion on the Finnish programme in this regard.

9.2 Great Britain

Great Britain has long taken the approach that active measures for deep disposal and for selecting a site for a repository for high-level radioactive waste should be put on hold for the time being (for a period of fifty years). This intention still applies, although recommendations have been made in recent years that this policy should be changed. The spent fuel is currently stored at the nuclear power plants and at Sellafield.

Even though Great Britain has consequently elected to take a passive position regarding high-level radioactive waste, detailed studies have been carried out on the deep disposal of low and intermediate level waste. Nirex is responsible for this work. It should be noted that this waste, which for the most part comes from the reprocessing plant at Sellafield, contains considerably larger amounts of long-lived radionuclides than the waste that is deposited in the Swedish repository for radioactive operational waste, SFR, in Forsmark.

Nirex' work has been concentrated on developing methods for disposing of waste and on finding a site for a deep repository. In 1987, the report "The Way Forward" was presented, which stated the principles for the siting process. In the initial phase, a great number of different types of geological media were considered for a repository. In 1989, two candidate sites were presented and in 1995, an application was submitted for permission to construct a research laboratory ("Rock Characterization Facility") at a prospective repository site at Sellafield in Cumbria. Nirex made the formal claim in the ensuing procedure (see below) that the application only pertained to a rock laboratory. In reality, this facility was a step in the investigation of the site's suitability as a repository and can be most closely compared with the detailed characterisation stage of the Swedish programme. The application had been preceded by site investigations at a cost of over 250 million pounds.

In accordance with the English system, it was up to Cumbria County to make a decision on this application. Permission was denied. When Nirex appealed the application, it had to be dealt with by a "Planning Inquiry" with procedures similar to a court of law. The negotiations, which continued for nearly six months, dealt with a large number of questions such as the siting process, the location of the facility on the edge of the protected "Lake District" and the safety of constructing a repository on this site. Cumbria County claimed, for example, that the siting process had been carried out with no insight from the public and that it was intentionally directed toward the site that Nirex preferred, considering its proximity to Sellafield.

Approximately one year after the negotiations had been concluded, the "Inspector" who had led the negotiations issued a report with recommendations to the government. In accordance with these recommendations, Nirex's application was denied for the reason that the site was not considered suitable for the intended purpose.

The nuclear waste programme in Great Britain must now be re-evaluated. One of the activities includes an evaluation by a committee, to the House of Lords. The government also has an

advisory committee, the Radioactive Waste Management Advisory Committee (RWMAC) at its disposal. The consequences of the re-evaluation remain to be seen. The siting process that Nirex carried out and the forms that public participation will take are among the questions being discussed. The English system, with its courtroom-like proceedings, does not encourage a dialog between the various parties such as the one in Sweden, which takes place within the framework of the Environmental Impact Assessment (EIA).

9.3 France

France has an extensive nuclear energy programme, with 29 reactors and a reprocessing facility in Le Hague. The volume of waste produced is commensurate and includes a large number of waste categories. The focus up until now has been to reprocess all spent fuel and to finally dispose of vitrified high level waste. A study published in 1995 however, indicates that France may consider depositing part of the nuclear waste directly, with no reprocessing. The government agency, ANDRA, has total responsibility for the waste programme. The French programme also includes research on transmutation and disposal near the ground surface. The French atomic energy agency, CEA, is responsible for this part of the programme.

After a systematic selection procedure in the 1980's, ANDRA chose four candidate sites for a repository. However, the plans were met by extensive protests in the selected areas, which led the government to temporarily stop the site selection programme. In 1991, Parliament passed a new law calling for the selection of two sites for underground laboratories, one of which might later be developed into a repository.

Christian Bataille, a Member of Parliament, was appointed as a mediator whose task was to enable the identification of these two sites. Bataille had the authority to provide the municipalities with 10-15 million francs in financial compensation yearly. After making a general study of geology and other conditions across the country,

Bataille issued a report naming a number of voluntary candidate municipalities.

After additional investigations, ANDRA proposed three sites. Hearings were held with local politicians and the public from the candidate municipalities as well as from neighbouring communities. ANDRA is now awaiting a decision from the government to start constructing laboratories on one or more of the sites. Despite the fact that the law from 1991 called for the construction of two laboratories, ANDRA now proposes that facilities be constructed on all three sites. A decision was expected in 1998.

The programme is reviewed each year by a specially appointed commission – the National Evaluation Commission (CNE), consisting of people with extensive scientific expertise in relevant areas. The commission has been critical to parts of ANDRA's programme. The criticism pertains particularly to one of the three prospective sites and the commission proposes that ANDRA select an alternative to the site in question. If ANDRA intends to build a repository on any of the sites, an application must be made to Parliament not later than 2006. CNE has also discussed the possibility of trial disposal for a limited period of time, which corresponds to the first step toward a repository in the Swedish programme.

9.4 Canada

The intention in Canada, as in Sweden, is to directly deposit spent nuclear fuel without reprocessing it. The repository is planned at a depth of between 500 and 1000 meters in crystalline bedrock. The programme has been divided into four phases: research, method evaluation, site selection and repository construction. Atomic Energy of Canada Ltd, AECL, is responsible for the programme, which has been very extensive and has included field studies and an underground laboratory.

The research phase was concluded in 1992, after which AECL was to produce an environmental impact statement (EIS) for the method of final disposal. This EIS was submitted to the authorities

in 1994, which initiated a period of comments from the public and a number of hearings. These hearings covered three phases: a phase of socio-political questions, a second phase pertaining to technology and a third phase of local hearings at a large number of locations throughout Canada. The purpose of this procedure was to evaluate AECL's concept for final disposal.

These hearings were held by the Canadian authority, who had appointed a panel for this purpose made up of experts in the areas of technology and sociology. The procedure also encompassed a system by which organisations and the public could apply for funds in order to be able to offer viewpoints on AECL's report.

The panel's report was published in March 1998. It was generally concluded that the final disposal system was considered to be technically acceptable but that it did not have the degree of acceptance necessary to enable the programme to proceed with site investigations. The panel offered a number of recommendations for obtaining public support, which included:

- Creating a new agency for managing nuclear waste
- Reviewing the requirements issued by the safety authority
- Establishing a plan for public participation
- Developing a procedure for ethical and social assessments
- Developing and comparing other alternatives for managing the spent nuclear fuel.

In the opinion of the expert panel, before this has been done and before a broader acceptance of the waste management has been reached, the siting process should not be continued. The government has not yet reached a decision in response to the panel's conclusions, but these conclusions must reasonably mean a serious setback for the nuclear waste programme in Canada.

9.5 Summary

This summary offers a divided account of the nuclear waste programmes in a number of countries. The programmes have met with significant setbacks in Canada and Great Britain, in Canada in terms of selecting a site and in Great Britain in the earlier phase of

determining a method for disposal. The programme in Switzerland has also met with similar problems.

On the other hand, the programme in Finland has been progressing according to plan for quite some time. Finland is preparing to select a site for a repository during 2000 and aside from the United States, has come closest to solving the waste problem. The site selection process is also underway in France which, however, will take longer since underground laboratories must first be built and be in operation for several years before a final site selection can be made. A site for a repository, Yucca Mountain in Nevada, has already been selected in the USA, where investigations of the bedrock are being carried out. The process in the US is difficult to predict due to complicated organisational considerations and because the state of Nevada still opposes the plans.

A common problem in many countries is establishing a suitable procedure to give the public insight into the programmes and the opportunity to participate in them. The re-evaluations that must be done in Canada and Great Britain must lead to solutions to this problem if the programmes are to proceed. There are other experiences, however. In France, the strong opposition that existed at the proposed sites has been replaced by a procedure giving the public greater influence, which up until now has basically been accepted by the local population. Site selection is proceeding according to plan in Finland, with close contacts with local residents.

There may be many reasons for differing situations in individual countries. KASAM has observed, however, that in both countries with the most stable programmes, the government and parliaments have taken clear responsibility. This was done in Finland through the decision by the Minister (on the goal of the investigation and timetable for final disposal) and in France by a new law governing site selection. Member of Parliament Bataille's mandate and skilful actions have played an important role in France. The decision that Parliament must make a new decision on the selection of a method by 2006 has probably contributed to increased confidence in the French programme.

The method used for public participation probably also plays a key role. In Great Britain, the process has contributed to a polarisation of the relationship between industry on the one hand and local authorities and environmental groups on the other. The Canadian system has facilitated participation but the review process has dealt with questions of system and method which have not been able to gain real local support. The new French siting process has lead to active local participation. The Finnish system shows a controlled EIA which nonetheless offers all parties a great deal of access to information and provides a forum for open dialogue.

10 EU’s research programmes

EU’s research programmes are conducted in the form of four-year Framework Programmes. The area of research pertaining to nuclear activities is called Nuclear Fission Safety and is carried out within the framework of the Euratom Treaty. The Fourth Framework Programme spanned the period between 1994 and 1997 and the Fifth Framework Programme is about to begin. Sweden’s membership in EU began in 1996 which means that Sweden has not had any real influence in planning the programme. It has, however, been possible to participate in projects, although to a lesser extent than would have been the case had Sweden been a member of EU during the entire duration of the programme.

In reality, the programme periods overlap in two ways. First of all, a number of projects that were begun during the latter part of the period will not be concluded until 1998 and 1999 and secondly, the initial application date for the Fifth Framework Programme is not until late in 1998.

10.1 The structure and implementation of the programme

EU’s research programmes are carried out for the most part in the form of ***Cost-Shared Actions***, which in most cases means that EU covers half of the research expenses while the other half must come from national funds. EU projects must also have participants from several countries. Consequently, a research organisation that is interested in starting an EU project must:

1 Find partners in other countries
2 Ensure that half of the project's expenses can be met by financiers in the individual countries (no decisions need to have been made, however, before an application is made)
3 Produce a complete project proposal outlining content and organisation. In reality, the initiator often becomes the co-ordinator.

The proposal is then reviewed by special reviewers who make a recommendation to the EC's Twelfth Directorate (DGXII) before a decision can be made. On occasion, this leads to proposed modifications of the project. If a project is approved, the co-ordinator is responsible for reporting on both costs and technical content to the EU.

It is also possible to apply for funds for ***Concerted Actions*** which means that EU supports the exchange of information between organisations within a certain area of research. In this case, no funds are provided for research. On the other hand, EU assumes all travel expenses, etc. The application and evaluation procedure is the same as for Cost-Shared Actions. On occasion, Concerted Action is used as a means of producing a basis for proposals for "real" projects, i.e. it becomes a feasibility study for a Cost-Shared Action.

10.2 The Fourth Framework Programme

Nuclear Fission Safety within the Fourth Framework Programme has been classified into the areas of reactor safety, radioactive waste management and disposal, radiological impact on man and the environment, exploring new concepts and historical liabilities (primarily Chernobyl). According to EU's CORDIS database, the entire programme comprises 148 projects, 45 of which relate to nuclear waste (April 1998).

A study of the database shows that a relatively large percentage (over 25%) of the projects that were initiated during the current programme period deal with categorising and managing different types of waste. Dismantling nuclear power plants and the

characteristics of clay are two other major areas that together comprise over 25% of the projects. The database otherwise shows a relatively large span of research questions pertaining to the area immediately surrounding a repository, geology, vitrification of waste and natural analogies. A small number of projects concern safety assessments.

For the segment of the programme concerning radiation protection, projects dealing with the biological impact of radiation make up a major part (30%). Dosimetry and measuring techniques are another relatively large area, encompassing approximately 20% of the projects. Other areas on the list of projects are studies of epidemiology, the ecosystem, radiation protection measures, radon and medical applications of radiation.

10.3 Sweden's participation

KASAM has used CORDIS for the purpose of forming an opinion on the Swedish participation in the Fourth Framework Programme. As a comparison with another country with similar conditions (i.e. became a member of EU at the same time, same concept for deep disposal, etc), Finland is also included in table 10.1 below. As the table shows, Sweden has participated in eight of the 45 waste projects that were in the database when the search was carried out (April 1998). Only one of these projects has a Swedish co-ordinator.

Table 10.1: Statistics on projects in the Nuclear Fission Safety Programme

Area	No. of Projects	No. of projects with Swedish participation	No. of projects with Finnish participation
Reactors	43	10	14
Nuclear waste	45	8	10
Radiation protection	35	13	5
Misc.	24	3	2
Total	147	34	31

The eight projects in the area of nuclear waste with Swedish participation deal with the following questions:

- Oklo phase 2 – study of the ways in which radionuclides move in bedrock after nuclear reactions in a "natural reactor";
- Source terms for safety assessments regarding spent nuclear fuel;
- Calculations and experiments regarding the properties of unsaturated clay;
- Microstructural and chemical parameters of bentonite clay, which are of significance to its characteristics as a barrier against the transport of radionuclides;
- Models for calculating the long-term safety of nuclear waste disposal in the geosphere;
- The transport of radionuclides in a natural flow system in Palmottu, Finland (an analogy to the way in which nuclides can move in the proximity of a repository);
- A study of fracture fills, which is of significance to the hydrology at a repository;

- A study of the possibilities of making hydrological predictions significant to the safety assessment of a repository, by analysing geo-chemical data, etc.

In addition, Sweden is participating in projects regarding separation and accelerator-based technology that provide knowledge of transmutation. A project on risk perception and risk communication is of particular interest. This is listed in the table under the heading "Miscellaneous". The project is co-ordinated by the Stockholm School of Economics.

10.4 The Fifth Framework Programme

The proposal that was available when this report was written indicated that the programme (Nuclear Fission Safety) would focus on:

- The safety and competitiveness of fission energy to improve the situation for European industry on the world market. New concepts with the potential for long-range advantages in terms of economic viability, safety, health and the environment,
- The safety and effectiveness of other industrial and medical applications of radiation as well as protection against natural sources of radiation.

The same proposal specifies five areas with specific issues:

– The safety and competitiveness of nuclear activities Ageing reactor systems, methods for testing and monitoring, modernisation of control systems, deep disposal, types of waste and actinide separation and transmutation;

– **Evaluating and managing risks**
Integrated risk analysis and dealing with uncertainties, probabilistic safety assessment, organisational aspects of safety, the influence of different parties (stakeholder involvement), forming a consensus on managing and disposing of nuclear waste;

– **Improving existing technology**

Passive safety systems, advanced control systems, new materials that reduce the need for maintenance, new fuels, smaller and less complicated reactors, optimising the nuclear fuel cycle;

– Innovative concepts

New concepts that provide advantages in terms of safety, waste management and a reduced risk for the spread of fissionable materials;

– Health and environment.

According to the budget proposed by the Commission (January 1998), fission and fusion programmes together will have a budget of approximately 1140 million ECU. It should be pointed out that the greater portion, approximately 80%, might be given to fusion research, which would give the fission programme a total budget of just under 200 million ECU for a four-year period.

10.5 Discussion

Sweden's involvement in eight nuclear waste projects in the Fourth Framework Programme may seem limited, even considering the fact that Sweden became a member of EU during the programme period. The Swedish waste programme has generally made considerable progress in comparison with most other EU countries, both in terms of installations and research. This could be a reason why EU research has not been given high priority in Sweden. Another factor could also be that international co-operation is being conducted in many other ways, for example, international research is being carried out at the Äspö Hard Rock Laboratory.

It is of special interest that Sweden, through the Royal Institute of Technology, is co-ordinating the research project "Impact of the accelerator-based technologies on nuclear fission safety". Chalmers University of Technology and Uppsala University are also taking part in the project. In this way, Sweden receives funds for research leading to increased knowledge of transmutation. The work is financed on a national level by the Swedish Nuclear Fuel and Waste Management Co (SKB).

However, the design of the Fifth Framework Programme may provide better conditions for increased Swedish involvement. The priorities that can be discerned in the new programme deal with questions of common interest to all countries with nuclear waste programmes and where international interaction can be particularly productive. There are other reasons for active involvement in EU's research. In general terms, EU funds in this area should become available to Swedish researchers. Involvement also provides the opportunity to influence both the programme and the conclusions that can be drawn from the research.

Finally, it should be pointed out that the research programme being conducted under the auspices of DGXII is not the only segment of EU's organisation where the question of nuclear waste is being dealt with. Extensive activities are still underway within DGXI which are more programme-oriented than research intensive. Both Swedish authorities and industry are actively involved here.

11 Can Sweden be compelled to accept foreign nuclear waste for final disposal?

Summary

Swedish legislation contains a provision which prohibits the final disposal of foreign waste in Sweden as a matter of principle. There are no indications that there is a sentiment – either within or outside of Parliament – that would favour changing this principle. A similar approach has been taken in other EU member states that have substantial nuclear energy production. When Sweden joined the EU, it was established that the Swedish legislation referred to is compatible with EU regulations. An international convention signed in autumn 1997 clearly recognises the right of each member state to make independent decisions regarding the import of foreign spent nuclear fuel and radioactive waste to its territory. At the same time, organisations representing the EU, as well as the International Atomic Energy Agency (IAEA), share the view that it is desirable for member states to co-operate to find and implement suitable solutions to questions regarding the final disposal of nuclear waste.

KASAM's conclusion is that the fears that Sweden could be compelled to accept foreign nuclear waste for final disposal against its will are unfounded. This conclusion is valid regardless of whether the nuclear waste originated in another EU member state or in another foreign country.

11.1 Background

It has sometimes been stated in the general debate that since having become a member of the EU[1], Sweden could be forced to accept foreign nuclear waste for final disposal.

A public information meeting was arranged by the Västerbotten county administrative board and the municipality of Malå in May 1997 with the theme "Where is the EU member states' nuclear waste disposed of?" This was part of an information campaign leading up to the local referendum on September 21, 1997 regarding the Swedish Nuclear Fuel and Waste Management Co's (SKB) site investigations in the municipality. Officials from the Swedish agencies with expertise in this area, the EC Commission's environmental directorate and the IAEA took part in the meeting. The following presentation is primarily based on the factual material which formed the basis for the talks given at this meeting.

Information that has been produced since the meeting mentioned above has also been used. The most important part of this information is the "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management" , which Sweden signed on September 29, 1997. The government is soon expected to propose that Parliament ratify this convention.

[1] Certain sections of this presentation assume that the reader is familiar with the basic structure of what since January 1, 1996 is the European Union (EU) and what before that time was the European Community (EC). The names used in this presentation for various agencies or organisations reflect what they were called at the time.

11.2 Swedish legislation prohibiting the final disposal of foreign nuclear waste in Sweden

According to Section 5 a of the Act on Nuclear Activities (1984:3), the final disposal of foreign nuclear waste is, as a matter of principle, prohibited in Sweden. The relevant provisions read as follows (unofficial translation):

> It is prohibited to, without special permission, finally dispose of within the Kingdom, spent nuclear fuel or nuclear waste generated by a nuclear facility or other nuclear activities in another land. The same applies to storage pending final disposal (interim storage). Permission may only be granted if particular grounds exist and the implementation of the programme intended in 12 § is not obstructed.
>
> With respect to permission for the export or import of nuclear waste, the restrictions stipulated in 20 a and 24 §§ of the Radiation Protection Act (1988:220) apply.

The background to this provision is as follows.

The Act on Nuclear Activities is based on the principle that all nuclear waste from the *Swedish* reactors should be managed in a safe manner *within* the country. Another principle is that *only* waste from the Swedish reactors should be handled in *our* country.

There is a similar approach, among all of the European nuclear power-producing countries, that each country should dispose of its own waste. Both Germany and Great Britain apply the principle that each country should be responsible for its own waste and that waste from other countries will not be accepted for final disposal. France has had legislation since 1991 stating that imported radioactive material may not be disposed of in France even if it has to be reprocessed there. In a response on October 10, 1996 to a question put to the European Commission, the Commission asserts that no member state has been forced to accept radioactive waste from other member states and that this principle should also be adhered to in the future.

It should be noted here that the concept of nuclear waste is not entirely unambiguous. According to the Act on Nuclear Activities, spent nuclear fuel is not nuclear waste since it contains nuclear substances that can be used to produce new nuclear fuel (reprocessing). Reprocessing is done in some countries but not, however, in Sweden. According to the definition used in the Act on Nuclear Activities, Swedish spent nuclear fuel does not become "nuclear waste" until it has been placed in a repository. The most common types of nuclear waste are filter resins, scrap and other industrial waste that has become radioactive. The concept "nuclear waste" is commonly applied to this type of waste as well as to high-level spent nuclear fuel.

Section 5 a of the Act on Nuclear Activities entered into force on January 1, 1993. In its original wording, this provision expressly prohibits the government from, with certain exceptions that will be dealt with shortly, granting a license for the final disposal of spent nuclear fuel or nuclear waste from a nuclear facility in another country. The provision was amended at a later date to also prohibit interim storage as of July 1, 1995.

11.3 How should the Swedish legislation on the ban be interpreted and applied?

To answer the question of how the Swedish legislation on the ban should be interpreted and applied, it is necessary to be familiar with the justifications that were presented to Parliament when Section 5 a was given its present wording in 1993 and 1995. These justifications can be found primarily in bill 1992/93:98 (and report 1992/93 NU 11) and in bill 1994/95:118 (and report 1994/95 NU 21). The primary implications of these documents are listed below.

Justification according to bill 1992/93:98 and report 1992/93 NU 11 on the ban on the final storage of foreign nuclear fuel or nuclear waste in Sweden

The bill points out (pp 29-30) that Parliament has on several occasions established as a basic principle for Sweden's actions that each country must take full responsibility for the nuclear waste produced in its own territory. Consequently, the final disposal of nuclear waste from nuclear activities in other countries may not be done in Sweden. It was observed that the principle had not been expressed in the Act on Nuclear Activities in its form at that time but that the principle "is a starting point for licensing regarding various ways of managing nuclear waste and nuclear substances". These basic principles for the Swedish policy on nuclear waste should now be stated in the law.

After a discussion of the most suitable legal solution to the question of formulating a ban, the government presented its deliberations on the international aspects of the question. As background to these deliberations, reports were presented on EU's regulations governing waste, IAEA's guidelines for international transactions with nuclear waste, the regulations in the Euratom Treaty, principles and laws used in Germany, Great Britain and France and a decision by the Court of Justice of the European Communities in a case involving the management of non-radioactive waste in the Walloon area of Belgium that originated in other countries. To summarise, the government felt that "neither Sweden's harmonisation with the EU nor Sweden's international obligations in general hinder the ban on the final disposal of foreign nuclear fuel and nuclear waste in Sweden" (bill p 32).

However, in the government's opinion, provision should be made for exceptions to this ban. Such provision "should be applied restrictively under exceptional circumstances " (bill p 33). A general point of departure for making such an exception, according to the bill, should be that "the total amount of material that could possibly be disposed of in Sweden may not, in terms of volume or radioactivity, exceed a small fraction of the estimated Swedish nuclear waste" (bill p 33).

Another guide as to the meaning of "exceptional circumstances" in this context can be found on page 46 of the bill: "Exceptional circumstances could arise if an overall assessment were to show it to be most suitable, from the point of view of safety or radiation protection, for the final disposal of a small amount of material in Sweden. This could pertain to testing e.g. fuel encapsulation or reactor components, in cases where very small amounts of waste have been generated or in cases involving secondary waste such as filter resins, etc that may be generated by processing at facilities in Sweden. Exceptions that are in conflict with the Swedish nuclear waste programme will not be sanctioned. This means both that the spent nuclear fuel or nuclear waste must be of a type that lies within the framework for the Swedish programme and that exceptions will be granted only for very limited amounts".

The Swedish Parliamentary Standing Committee on Industry and Commerce (report 1992/93:NU 11) concurred with the government's opinion both regarding the proposed ban on final disposal and the need of an exemption clause. Regarding the exemption clause, the committee wanted to "emphasise the importance of the fact that such exceptions will be made extremely restrictively" (report p 5).

Justification according to bill 1994/95:118 and report 1994/95 NU 21 on the ban on interim storage of foreign nuclear fuel or nuclear waste in Sweden

In bill 1994/95:118, the government proposed that the ban on the final disposal of foreign nuclear waste in Sweden set out in Section 5 a of the Act on Nuclear Activities should be expanded to include interim storage while awaiting final disposal.

As justification, it was stated (p 18) that interim storage is "a step in the final management of the waste. It is one of the final stages in the nuclear fuel cycle. Therefore, the principle that each state should take full responsibility for its own waste must apply to interim storage as well. The import and interim storage of foreign material in Sweden for final disposal abroad at a later date is also unsuitable as a matter of principle, considering the lengthy period of

time involved in interim storage. Nor has the Swedish programme for the final management of spent nuclear fuel and nuclear waste been designed for such treatment."

The bill also dealt with the question of whether or not the ban on interim storage of foreign material could conflict with EU's regulations. It states (p 18) "that the deliberations by the government prior to the decision on the ban on final disposal (bill 1992/93:98 p 29) also apply to interim storage. A ban on interim storage does not violate the Euratom treaty or other EU regulations. That the conclusions stated in the bill are valid is also supported by the above-mentioned Community declaration". (An account of this declaration is given below in section 11.4).

It was also especially pointed out (bill p 18) that the ban only concerns "interim storage pending final disposal. It should not include interim storage in Sweden of foreign spent nuclear fuel or nuclear waste for a limited period of time for other purposes, e.g. if the material is to be used in different types of investigations. Material stored as a phase in a treatment process should also be excluded. A process in this context is a procedure to change the characteristics of the waste in terms of volume, form, radioactive content, chemical make-up, etc. In such cases, it is not a question of measures that can be considered part of the final management of spent nuclear fuel or nuclear waste."

An additional clarification of the ban is made on page 26 of the bill. In reference to the statement in the previous paragraph, it is recalled that the ban does not include "storage for a limited period of time for other purposes, such as if the material is to be examined or treated here. If the storage is intended to reduce radioactivity or cool the material in preparation for final disposal, the principle applies, even if there are other reasons for storing the material in Sweden. In reality, to be able to speak in terms of interim storage pending final disposal, the storage must be carried out over a relatively long period of time."

The Swedish Parliamentary Standing Committee on Industry and Commerce (report 1994/95:NU 21) supported the bill and referred to the committee's statements of 1992 in connection with the ban on final disposal.

Example of a government decision according to the exemption clause in Section 5 a of the Act on Nuclear Activities concerning licensing for the final disposal or interim storage of foreign spent nuclear fuel or nuclear waste

The government's decision in 1994 is an example of an application of the exemption clause as a result of Studsvik AB's application for a license for the final disposal of foreign nuclear fuel, including secondary waste, which was a component of the material undergoing various tests at Studsvik. The government agreed that a maximum of 25 kg spent nuclear fuel and a maximum of 250 kg low-level nuclear waste originating from foreign nuclear activities (and brought into Sweden between December 1994 and June 1997) could be finally disposed of in Sweden. The justification for this decision was the fact that Studsvik's activities gave rise to the development of a certain competence that was of value to Sweden, that returning the waste in question would cause a certain exposure to radiation and that the amounts of material involved were inconsequential in relation to the Swedish programme for final disposal. These conditions were considered to constitute the "exceptional circumstances" required by law for making an exception to the basic rule of not allowing the final disposal of foreign nuclear waste in Sweden. The government's decision was in accordance with the Swedish Nuclear Power Inspectorate's (SKI) statement in this matter. In a later decision (1996), the government allowed the amount of uranium to be increased to 50 kg.

The board of SKI, which deals with matters of this type, has shown great interest in the question and has also declared that a very restrictive attitude should be taken in these matters.

11.4 The government's assessment of the Swedish ban's consistency with regulations within EU

The question of whether the provisions of the Act on Nuclear Activities are consistent with EU regulations is dealt with specially, in bill 1994/95:19 on Sweden's membership in the European Union, and in bill 1994/95:118 on legislation regarding Sweden's inclusion in Euratom.

In bill 1994/95:19, the government proposed that the Parliament ratify the membership treaty and the final act of the treaty between EU's member states at that time and the countries that had applied for membership: Norway, Austria, Finland and Sweden. The bill contained a detailed report on the Swedish deliberations and viewpoints during the negotiations that took place before Sweden was admitted to the EU on January 1, 1996.

It is of particular interest in this context to report on the deliberations that were made against the background of the wording of the treaty of March 25, 1957 on the establishment of Euratom, as well as the revisions that were made later.

It was stated (bill pp 275-277) that one of the important starting points for Sweden during membership negotiations was that Sweden would be able to pursue its own policies on nuclear power and on managing nuclear waste, that the Euratom treaty was antiquated in certain respects and that certain sections of the treaty were not being applied literally.

The membership negotiations resulted in an agreement between Sweden and the member states on a common declaration regarding the application of the Euratom treaty. This declaration can be found in the bill (p 276 and as appendix 11, p 8) and reads as follows:

Joint Declaration on the application of the Euratom Treaty

> The Contracting Parties, recalling that the Treaties on which the European Union is founded apply to all Member States on a non-discriminatory basis and without prejudice to the rules governing the

> internal market, acknowledge that, as Contracting Parties to the Treaty establishing the European Atomic Energy Community, Member States decide to produce or not to produce nuclear energy according to their specific policy orientations.
>
> As regards the back end of the nuclear fuel cycle, it is the responsibility of each Member State to define its own policy.

Through this joint declaration, Sweden, in the opinion of the government, "has achieved its intended objectives in the negotiations" (bill p 277).

The wording of the provision in the Act on Nuclear Activities that prohibits the final disposal in Sweden of foreign spent nuclear fuel and nuclear waste (Section 5 a) was also commented on in the bill (p 280): "A similar ban has been in effect since December 1991 in France. A ban of this type is not contrary to the Euratom treaty. Consequently, the regulations within the EC on radioactive waste do not affect the policies that Sweden will pursue in regard to the management and final disposal of radioactive waste and spent nuclear fuel".

In this regard, the bill also stated that a Community Plan of Action exists in the field of radioactive waste, encompassing the period 1993-1999 and that this plan is intended to supplement the EU’s research and development plan.

To summarise, the government made the following assessment of Euratom in this bill (p 275):

> The conditions in the field of nuclear energy are completely different to those that existed when the Euratom treaty was signed in 1957. This has made certain sections of the Euratom treaty antiquated.
>
> Membership in Euratom does not affect the policies that Sweden intends to pursue in regard to nuclear power and managing nuclear waste. Only limited changes will have to be made to Swedish legislation as a consequence of membership. The government will present a proposal to Parliament regarding the necessary changes in the legislation.

Proposals for a number of minor changes to laws were presented in bill 1994/95:118 on legislation regarding Sweden's membership in Euratom.

Only one of these proposals is of interest in this context. It pertained to the ban on interim storage of foreign spent nuclear fuel and nuclear waste in Sweden (see the previous section).

The bill also lists a number of general viewpoints on the need for legislation (pp 9-11). Criticism expressed by the Swedish Society for Nature Conservation was reported here. The criticism pertained to the fact that the basis for the decision and the review procedure had been inadequate and that the decision should be based on "a publicised and reviewed systematic examination of the Union's current legal acts in this area" The government stated that the results of negotiations in the Euratom area as well as the contents of the treaty and of legal acts under Euratom had been reported in the bill on EU membership and continued by saying (p 11): "The negotiations on membership have resulted in a joint declaration on the application of the treaty, where certain basic questions on the treaty's application are clarified…..A more thorough examination of the Euratom treaty and secondary legal acts in this area fall outside of the framework of this piece of legislation. The proposals made in this context are primarily intended to change legislation when necessary in order to supplement the Euratom regulations that have a direct effect."

11.5 Other statements by the government on the Swedish ban's consistency with regulations within the EU

The Swedish government's position on the final disposal or interim storage in Sweden of foreign spent nuclear fuel or nuclear waste has also been expressed in contexts other than bills to Parliament. The following is a *first* example:

The Council of Ministers of the European Union adopted a resolution on December 19, 1994 on the radioactive waste

management (Council Resolution on radioactive-waste management, 94/C 379/01). The following declaration was made by Sweden before the decision was made:

SWEDISH DECLARATION IN CONNECTION WITH THE COUNCIL RESOLUTION ON RADIOACTIVE WASTE MANAGEMENT

Sweden will in connection with the adoption of the Resolution on Radioactive Waste Management make the following statement:

Sweden considers Radioactive Waste Management to be a national responsibility. This principle was strongly emphasized by Sweden in the negotiations on membership of the European Union and led to a joint declaration by the Parties on the application of the Euratom Treaty, as part of the Final Accession Act. The Joint declaration states that:

As regards the back end of the nuclear fuel cycle, it is the responsibility of each Member state to define its own policy.

Sweden´s interpretation of the Treaties and the declaration in the Accession Act includes:

- each Member State´s right to prohibit the final disposal of foreign spent nuclear fuel and nuclear waste on its territory,
- each Member State´s sole right to decide whether to enter into cooperation arrangements with other Member States on disposal of spent nuclear fuel and nuclear waste and on the scope and aim of such cooperation.

As a consequence of this policy Swedish legislation prohibits the final disposal of foreign spent nuclear fuel and nuclear waste on Swedish territory. The Swedish government has also proposed a ban on the interim storage of such foreign spent nuclear fuel and nuclear waste that is pending final disposal.

A *second* example refers to the Community Plan of Action for the years 1993-1999, mentioned in section 11.4, in the Field of Radioactive Waste. A standing committee, the Advisory Committee on Programme Management (ACPM) has the task

within the EU of advising the Commission on matters pertaining to the previously mentioned Plan of Action.

In a letter from the Ministry of the Environment to the Commission in connection with a meeting with ACPM in December 1996, an explicit reference was made to the Swedish declaration mentioned in the first example, which is also reproduced in its entirety in the letter. The Swedish viewpoint has been reiterated at subsequent meetings with ACPM.

11.6 The EU perspective

The Euratom Treaty, etc

The treaty establishing the European Atomic Energy Community, Euratom, was signed in 1957 along with the Treaty of Rome. The Euratom treaty today is an integral part of the EU member states' legal systems but the treaty is antiquated in certain respects. Attempts have been made to modernise it but have broken down due to disagreements between the member states on nuclear power policy.

Questions on managing the radioactive waste generated by nuclear energy was given little attention when the treaty was signed. However, there is a provision in article 37, according to which the member states have an obligation to inform the Commission of their plans for the disposal of radioactive waste in order to provide a basis for assessing if radioactive releases to the air, water or soil pose a threat to neighbouring states. In a recommendation (91/4) on the application of this article, the Commission has given a more detailed description of the types of facilities that may be covered by the provision and the type of information that should be sent to the Commission. The Commission must present any opinions that it may have within six months. However, this is not a licensing action.

Of the directives that have been issued as a result of the treaty, the one that is of particular interest in this context concerns monitoring the transport of radioactive waste between member

states as well as transporting this material into and out of the EU (directive 92/3/Euratom). The directive deals with the permits and documents needed in connection with the transport of radioactive waste from one member state to another. The country receiving the waste must give its approval before the transport may be carried out[2] .

There is also reason in this case to again refer to the "Community Plan of Action in the Field of Radioactive Waste" that the Council adopted in the resolution of June 1992, which applies to the period of 1993-1999. One of the plan's objectives is to promote co-operation among member states in regard to the safe management and final disposal of radioactive waste. In addition to this plan of action, there is a communiqué from the European Commission of March 1994 to the Council, Parliament and the Economic and Social Committee (A Community Strategy for Radioactive Waste Management) and the previously mentioned Council resolution of December 1994.

As with the strategy paper and resolution of 1994, the plan of action for 1993-1999 is a political document that stresses the desirability of co-operation among member states and between the EU and other non-member countries. It is emphasised that each member state has the responsibility for ensuring that domestic radioactive waste is properly managed, while also pointing out the fact that there are possibilities for voluntary co-operation among member states. The Council has also emphasised the optimum use of national waste facilities and, in appropriate cases, co-operation among member states.

The following excerpt from the Commission's strategy paper of March 1994 (COMM (94)66 final) illustrates this viewpoint. Under the heading "Self-sufficiency in Radioactive Waste Disposal and Community Solidarity), it states:

[2] It should be mentioned that this directive has been integrated into the Swedish legal system through the Swedish Radiation Protection Institute´s (SSI) regulations for import/export controls for nuclear waste (SSI FS 1995:4)

The principle of self-sufficiency in disposal is also a part of the EC strategy for non-radioactive waste … The aim of self-sufficiency at Community level holds good for radioactive waste. It would be irresponsible for an advanced economic unit of the size of the Community not to dispose of its own waste. The Community is already party to agreements which prohibit the export of radioactive waste to the ACP States (IVth Lomé Convention) and the Overseas Community Territories. Equally the Community would be justified in refusing to accept radioactive waste from other countries as far as it would result for ever in a net import of an additional load of radioactive material.

Self-sufficiency at national level is established policy in some Member States. Whilst Member States should certainly aim individually at being able to dispose of their own radioactive waste, it seems however regrettable, and at least premature, to deny the possibility of assistance to another country of the Community in specific cases, notably those putting at stake nuclear safety. This suggests a more open approach to the disposal question. Such an approach has been recommended by the Commission several years ago. It was noted that a regional approach, involving several countries, could offer advantages especially to countries that have no or limited nuclear programmes insofar as it would prevent disposal projects, unjustified on economic grounds, being undertaken on an individual basis.

It appears therefore that the exercise of Community solidarity in these disposal matters should be kept open.

Action

Develop a solidarity approach to disposal (especially for high level waste).

The Council dealt with the Commission's strategy paper in December 1994 and as a result issued the following statement in resolution 94/C 378/01:

THE COUNCIL OF THE EUROPEAN UNION,

Recalling the Commission communication on a Community strategy for radioactive-waste management,----,

Notes that all Member States produce radioactive waste to varying degrees, and that significant quantities of radioactive waste have already been built up in the Community, awaiting disposal,

1. WELCOMES the fact that the Commission has put forward a communication proposing elements of a Community strategy in implementation of the Community plan of action in the field of radioactive waste;

2. TAKES THE VIEW that each Member State is responsible for ensuring that the radioactive waste produced on its territory is properly managed and NOTES that, in this context, the possibility of a mutually agreed cooperation between Member States exists;

---

5. TAKES THE VIEW that Community research programmes .... should be given appropriate priority and that cooperation in research and development between Member States should be intensified in order to contribute to improved solutions for the management of radioactive waste;

6. EMPHASIZES that the establishment of suitable facilities for the treatment, conditioning, storage and final disposal of radioactive waste makes a necessary and important contribution to the creation of a safe waste-management infrastructure in general;

CONSIDERS that optimum use should be made of facilities at national level and, where practicable and appropriate, between Member States, bearing in mind the political aspects of the matter and that further consideration should be given to the various approaches available, which might result, among other things, in a minimization of transport of radioactive waste;

The Commission's statement of autumn 1996 on the view of national regulations for the final disposal of nuclear waste

In the autumn of 1996, the Swedish European Parliament member, Per Gahrton, presented a written question (E-2167/96) to the Commission, regarding "Final disposal of waste from nuclear power operations in another member state". The question refers to a report submitted by a consultant which claims that there are neither directives nor precedent-setting court decisions that regulate the export of nuclear waste for final disposal between EU member states. According to the report, this means that "Sweden could become an importer of nuclear waste" (an unofficial translation of Gahrton's quote in the report). According to Gahrton, certain named officials at the Commission had stated that "The Commission believes that in the future, a small number of countries in Europe will take responsibility for final disposal and therefore see nothing negative in such a scenario".

Gahrton posed the following question: "Is it the Commission's objective that the final disposal of nuclear waste in the EU should be concentrated to a small number of countries? Does the Commission consider that the final disposal of nuclear waste can and should take place in a member state that has not itself been the source of the waste? Will a member state that has nuclear energy and therefore its own nuclear waste to manage be able to refuse to accept waste from another member state solely on the basis of a political decision not to import nuclear waste for final disposal? Or will such an action be considered a breach of the principle of the Internal Market and lead to intervention by the Commission?"

The response was given by Commissioner Ritt Bjerregaard on October 10, 1996. It is evident from the response that valid regulations exist in a directive on the monitoring and control of the transport of radioactive waste between member states and into and out of the EU (Dir. 92/3/Euratom). According to this directive, permits from the member-country-of-origin are required for all transports. This type of permit can only be issued after the country-of-destination has given its approval.

In her response, Bjerregaard also referred to the communiqué from the European Commission of March 1994 to the Council, Parliament and the Economic and Social Committee regarding "A Community Strategy for Radioactive Waste Management".[3]

It was stated in this communiqué that, in many cases, it may be necessary to concentrate the management and storage facilities and repositories for radioactive waste for financial, safety or environmental reasons and that the number of such facilities will be very limited. Bjerregaard said that, in the opinion of the Commission, the possibility for voluntary co-operation between member states to limit the number of repositories should be kept open.

It was also pointed out in the response that only those member states that have nuclear energy production are sources of "nuclear waste" while all member states are sources of radioactive waste from medical activities, etc. The response also refers to the Council Resolution of December 19, 1994 mentioned above, regarding the management of nuclear waste, where it is stated that each member state is responsible for ensuring that its own radioactive waste is dealt with in a suitable fashion but where it also noted that the possibility exists for mutually agreed upon co-operation between member states. Finally, Bjerregaard states that up to the present, the EU has not forced any member state to accept radioactive waste from other member states and that the Commission feels that this should remain the case.

The response in the European Parliament of November 10, 1997 to a question posed by a Swedish member regarding the transport of radioactive waste within the EU

The question posed by the Swedish member of the European Parliament, Hans Lindqvist, regarding the transport of radioactive waste within the EU (H-0781/97) was responded to on November 19, 1997 by a representative of the Council.

[3] This is the same communiqué that was mentioned in the previous section of this chapter.

Lindqvist's question was based on the directive 96/29/Euratom (EGT L 159, 29.6.1996, pp 1-114), the Basic Safety Standards, where, according to Lindqvist, Germany, France or England would be free to store their radioactive waste in one of the storage facilities in Sweden. Lindqvist wondered if this interpretation was correct and if countries with suitable bedrock could become waste stations for all of Europe.

The Council representative for the Chair country, Wohlfart, declared that directive 96/29/Euratom contained basic standards for the health protection of the public and of employees in regard to the dangers that may arise from ionising radiation. In the question of transporting radioactive waste, he referred to directive 92/3 Euratom, pertaining to the monitoring and control of transports of radioactive waste between member states, which provides a strict control system. Transport between member states can only be carried out after the proper authorities in the member state that is to receive the material have given their approval.

Lindqvist said that he interpreted the response to mean that the Council's representative claims that there are no risks that radioactive waste could inadvertently be brought into any member state that has not approved the import of such material from other countries. He characterised Wohlfart's statement as "a positive response which I look forward to passing on in Sweden". In the ensuing discussion, Wohlfart emphasised that the most important matter is the ”provision laying down the responsibilities and competences of the recipient Member State”. He pointed out that this regulation means for example, that if Sweden does not accept a transport of this type, the country is protected from any storage of radioactive waste.

In this context, Wohlfart recalled that this principle had been "very vigorously" defended by Sweden during its membership negotiations. He also referred to the Swedish statement attached to the final membership application "As regards the back end of the nuclear fuel cycle, it is the responsibility of each member state to define its own policy" (cf. section 11.4 above).

Another Swedish member of the European Parliament, Jonas Sjöstedt, posed an additional question during the course of the

debate: "If a situation should arise where Sweden or any other country refuses to accept a transport of radioactive waste, can this decision be appealed to the Court of Justice of the European Communities? If so, can the Court overturn the decision of the member state to refuse to accept the radioactive waste?" Wohlfart's reply was that, in regard to this matter, if a problem arises with respect to European Union legislation, in his opinion, the Court should be able to try the case.

11.7 Convention on the safety of spent nuclear fuel management and the safety of radioactive waste management

At the International Atomic Energy Agency's (IAEA) general conference in 1994, a proposal was adopted that provided a starting point for work on a convention on radioactive waste. In March 1995, IAEA's board decided that the work should commence and called together a group of technical and legal experts. A proposed wording for this convention was gradually produced. The proposal, finally called "Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management" was opened for signature at IAEA's general conference in Vienna on September 29, 1997. Sweden signed the convention on the same day.

The government is expected shortly to propose that Parliament ratify the convention. It enters into force ninety days after 25 countries, of which 15 must have at least one operational nuclear power plant, have ratified the convention. According to a memorandum from the Swedish Nuclear Power Inspectorate (SKI), it is not expected to enter into force until sometime during 1999.

The convention encompasses matters of safety regarding the management of spent nuclear fuel and radioactive waste originating from civilian activities. One basic premise is that problems

pertaining to spent nuclear fuel and radioactive waste should be dealt with by the generation that caused the problems and that these problems should not be transferred to future generations. To achieve this, the convention obliges the signatories to fulfil certain commonly accepted safety and radiation protection principles. These principles have been expressed in the form of e.g. international standards or guidelines from the IAEA, etc.

In the preamble to the convention, a number of basic principles are stipulated that are intended to provide guidance for the parties to the convention. The following are excerpts from those sections of the preamble that are of greatest interest in this context.

THE CONTRACTING PARTIES

(vii) Recognizing that the definition of a fuel cycle policy rests with the State, some States considering spent fuel as a valuable resource that may be reprocessed, others electing to dispose of it;

(ix) Affirming the importance of international co-operation in enhancing the safety of spent fuel and radioactive waste management through bilateral and multilateral mechanisms, and through this incentive Convention;

(xi) Convinced that radioactive waste should, as far as is compatible with the safety of the management of such material, be disposed of in the State in which it was generated, whilst recognizing that, in certain circumstances, safe and efficient management of spent fuel and radioactive waste might be fostered through agreements among Contracting Parties to use facilities in one of them for the benefit of the other Parties, particularly where waste originates from joint projects;

(xii) Recognizing that any State has the right to ban import into its territory of foreign spent fuel and radioactive waste;

It can be stated that the convention does emphasise the importance of international co-operation in the question of dealing with spent nuclear fuel but at the same time – in point xii – clearly recognises each state's right to make its own decisions on the import of foreign spent nuclear fuel to its territory.

11.8 Conclusions

In conclusion, this chapter shows the following:

- Swedish legislation contains a provision expressing the principle of prohibiting the final disposal of foreign nuclear waste in Sweden.
- A similar approach exists in other EU member states with significant nuclear power production.
- When Sweden became a member of the EU, it was established that Swedish legislation was consistent with EU legislation.
- An international convention was signed in autumn 1997 unequivocally recognising the right of each state to make its own decisions on the import of foreign spent nuclear fuel and radioactive waste to its territory.
- Both the European Commission and the Council are of the opinion that the possibilities exist for voluntary co-operation between member states on the final management of radioactive waste, which is also stated in the convention mentioned above.

KASAM's conclusion is that the fears that Sweden could be compelled to accept foreign nuclear waste for final disposal against its will are unfounded. This conclusion is valid regardless of whether the nuclear waste originated in another EU member state or in another foreign country.

The European Commission and Council have expressed the opinion that co-operation between member states is desirable for the purpose of finding and implementing appropriate solutions to the management of radioactive waste. The IAEA favours solutions based on international co-operation. Co-operation in the sense that

nuclear waste from one of the EU member states should be accepted for final disposal by another member state assumes, however, that a voluntary agreement has been reached between the two countries involved. There are basic provisions in Swedish legislation prohibiting the final disposal of foreign nuclear fuel and nuclear waste in Sweden. There are no indications that there is a sentiment – either within or outside of Parliament – that would favour changing this principle.

KASAM

STATENS RÅD FÖR
KÄRNAVFALLSFRÅGOR
Swedish National Council for Nuclear Waste

KASAM, the Swedish National Council for Nuclear Waste – established in 1985 – is an independent committee attached to the Ministry of the Environment. KASAM's task is to investigate issues relating to nuclear waste and the decommissioning of nuclear installations and to provide the Government and certain regulatory authorities with advice on these issues.

KASAM's members – who largely comprise professors from Swedish and Nordic universities and institutes of technology – represent independent expertise within different areas of importance for the disposal of radioactive waste, not only in natural science and technology but also in areas such as psychology, ethics, law and social sciences.

KASAM is responsible for evaluating the programme for research and development – concerning the final disposal of spent nuclear fuel – which the Swedish nuclear power utilities present every three years.

KASAM is also responsible for presenting a special independent evaluation of the state of knowledge within the nuclear area every three years. This publication contains the state-of-the-art reports for 1998.

The report is available in Swedish and in English.

KASAM, Ministry of the Environment, S-103 33 STOCKHOLM, SWEDEN

FRITZES
OFFENTLIGA
PUBLIKATIONER

POSTADRESS: 106 47 STOCKHOLM
FAX 08-690 91 91. TELEFON: 08-690 91 90
E-POST: fritzes.order@liber.se
FRITZES INTERNETBOKHANDEL: WWW.FRITZES.SE

ISBN 91-38-21107-6
ISSN 0375-250X