Geological Repository Systems For Safe Disposal Of Spent Nuclear Fuels And Radioactive Waste Woodhead Publishing Series In Energy

Deep Geological Disposal of Radioactive Waste presents a critical review of designing, siting, constructing and demonstrating the safety and environmental impact of deep repositories for radioactive wastes. It is structured to provide a broad perspective of this multi-faceted, multi-disciplinary topic: providing enough detail for a non-specialist to understand the fundamental principles involved and with extensive references to sources of more detailed information. Emphasis is very much on “deep geological disposal – at least some tens of metres below land surface and, in many cases, many hundred of metres deep. Additionally, only radioactive wastes are considered directly – even though such wastes often contain also significant chemotoxic or otherwise hazardous components. Many of the principles involved are generally applicable to other repository options (e.g. near-surface or on-surface disposal) and, indeed, to other types of hazardous waste. Presents a current critical review in designing, siting, constructing and demonsrating the safety and environmental impact of deep repositories for radwaste Addresses the fundamental principles of radioactive waste with up-to-date examples and real-world case studies Written for a multi-disciplinary audience, with an appropriate level of detail to allow a non-specialist to understand

Understanding the behaviour of gases in the context of radioactive waste disposal is a fundamental requirement in developing a safety case for the disposal of radioactive waste. Of particular importance are the long-term performance of bentonite buffers and cement-based backfill materials that may be used to encapsulate and surround the waste in a repository, and the behaviour of plastic clays, indurated mudrocks and crystalline formations that may be the host rocks for a repository. The EC Euratom programme funded project, FORGE, has provided new insights into the processes and mechanisms governing gas generation and migration with the aim of reducing uncertainty. This volume brings together papers on aspects of this topic arising from both the FORGE project and work undertaken elsewhere. This has been achieved by the acquisition of new experimental data coupled with modelling, through a series of laboratory and field-scale experiments performed at a number of underground research laboratories throughout Europe.

This volume contains 11 case studies of toxic waste repositories that use geologic isolation in order to accomplish the permanent and safe isolation of dangerous materials. It describes past and currently active facilities and also discusses generic considerations of the isolation capability of average crustal rock, apparently in an effort to convince audiences of the safety of these facilities. Key components of the nuclear fuel cycle are short-term storage and long-term

disposal of nuclear waste. The latter encompasses the immobilization of used nuclear fuel (UNF) and radioactive waste streams generated by various phases of the nuclear fuel cycle, and the safe and permanent disposition of these waste forms in geological repository environments. The engineered barrier system (EBS) plays a very important role in the long-term isolation of nuclear waste in geological repository environments. EBS concepts and their interactions with the natural barrier are inherently important to the long-term performance assessment of the safety case where nuclear waste disposition needs to be evaluated for time periods of up to one million years. Making the safety case needed in the decision-making process for the recommendation and the eventual embracement of a disposal system concept requires a multi-faceted integration of knowledge and evidence-gathering to demonstrate the required confidence level in a deep geological disposal site and to evaluate long-term repository performance. The focus of this report is the following: (1) Evaluation of EBS in long-term disposal systems in deep geologic environments with emphasis on the multi-barrier concept; (2) Evaluation of key parameters in the characterization of EBS performance; (3) Identification of key knowledge gaps and uncertainties; and (4) Evaluation of tools and modeling approaches for EBS processes and performance. The above topics will be evaluated through the analysis of the following: (1) Overview of EBS concepts for various NW disposal systems; (2) Natural and man-made analogs, room chemistry, hydrochemistry of deep subsurface environments, and EBS material stability in near-field environments; (3) Reactive Transport and Coupled Thermal-Hydrological-Mechanical-Chemical (THMC) processes in EBS; and (4) Thermal analysis toolkit, metallic barrier degradation mode survey, and development of a Disposal Systems Evaluation Framework (DSEF). This report will focus on the multi-barrier concept of EBS and variants of this type which in essence is the most adopted concept by various repository programs. Empasis is given mainly to the evaluation of EBS materials and processes through the analysis of published studies in the scientific literature of past and existing repository research programs. Tool evaluations are also emphasized, particularly on THCM processes and chemical equilibria. Although being an increasingly important aspect of NW disposition, short-term or interim storage of NW will be briefly discussed but not to the extent of the EBS issues relevant to disposal systems in deep geologic environments. Interim storage will be discussed in the report Evaluation of Storage Concepts FY10 Final Report (Weiner et al. 2010).

This Special Publication highlights the importance of clays and clayey material, and their multiple roles, in many national geological disposal facilities for higher activity radioactive wastes. Clays can be both the disposal facility host rock and part of its intrinsic engineered barriers, and may be present in the surrounding geological environment. Clays possess various characteristics that make them high-quality barriers to the migration of radionuclides and chemical contaminants, e.g. very little water movement, diffusive transport, retention capacity, self-sealing

capacity, stability over millions of years, homogeneity and lateral continuity.
A key challenge in the development of safety cases for the deep geological disposal of radioactive waste is handling the long time frame over which the radioactive waste remains hazardous. The intrinsic hazard of the waste decreases with time, but some hazard remains for extremely long periods. Safety cases for geological disposal typically address performance and protection for thousands to millions of years into the future. Over such periods, a wide range of events and processes operating over many different timescales may affect a repository and its environment. Uncertainties in the predictability of such factors increase with time, making it increasingly difficult to provide definite assurances of a repository's performance and the protection it may provide over longer timescales. Timescales, the level of protection and the assurance of safety are all linked. Approaches to handling timescales for the geological disposal of radioactive waste are influenced by ethical principles, the evolution of the hazard over time, uncertainties in the evolution of the disposal system (and how these uncertainties themselves evolve), and the stability and predictability of the geological environment. Conversely, the approach to handling timescales can affect aspects of repository planning and implementation including regulatory requirements, siting decisions, repository design, the development and presentation of safety cases and the planning of pre- and post-closure institutional controls such as monitoring requirements. This is an area still under discussion among NEA member countries. This report reviews the current status and ongoing discussions of this issue.
The international Mont Terri rock laboratory in Switzerland plays a central role in the safety and construction of deep geological nuclear repositories in clay formations. The laboratory has developed and refined a range of new measurement and evaluation methods: it has e.g. advanced the determination of rock parameters using innovative borehole geophysics, improved the methodology for characterizing pore-water and microbial activity in claystones, and greatly improved our understanding of diffusion and retention processes of radionuclides in and through claystones. The methods and insights described in this compendium can also be applied to low-permeability rocks at various sites around the globe, and in other fields of application.
With over forty chapters, written by leading scholars, this comprehensive volume represents the best work in America, Europe and Asia. Geographical diversity of the authors is reflected in the different perspectives devoted to the subject, and all major disciplinary developments are covered. There are also sections concerning the countries that have made the most significant contributions, the relationship between science and industry, the importance of instrumentation, and the cultural influence of scientific modes of thought. Students and professionals will come to appreciate how, and why, science has developed - as with any other human activity, it is subject to the dynamics of society and politics.
This handbook is concerned with developing principles and standards for the

safe disposal of solid radioactive wastes by burial deep in the Earth's crust. Radioactive wastes have focussed thinking on long-term environmental protection issues in an unprecedented way. Consequently, the way in which principles and standards are set, and the thinking behind this, is of wider interest than to the nuclear field alone. The issues are not just technical and scientific. There is also a much wider philosophical context to the debate, centering on ethics, human values and the expectations of society. In this handbook it is intended that all theses issues are brought together, suggesting appropriate ways forward in each area, culminating in a proposed structure for safety regulations. It also aims to provide a detailed discussion of some of the most difficult logical an ethical issues facing those wishing to dispose of long-lived radioactive wastes.

Understanding in detail the ion partitioning in mineralwater interactions is of fundamental importance to geochemical studies and ultimately to society. The solid-solution properties of minerals are a significant part of the complexity, and also the importance, of these ion-partitioning reactions.

Introducing the Quality of Protection Modeling Language (QoP-ML), this book provides for the abstraction of security systems while maintaining emphasis on the details of quality protection . It delineates the steps used in cryptographic protocol and introduces a multilevel protocol analysis that expands current understanding. Every operation defined by QoP-ML is described within parameters of security metrics, therefore evaluating the impact of the operation on the entire system's security.

This report considers key safety issues regarding the geological disposal of radioactive waste and focuses on the different functions of a repository within its life cycle. It describes the processes relevant to the containment of long-lived radioactive waste and other processes that might affect the long term integrity of the repository. Chapters include discussion of: the geological disposal concept; near field components and processes; far field barriers and processes; safety and performance assessments.

This book describes repository solutions for all types of radioactive waste and residues in different geotechnical repository structures. The focus is initially on existing or planned final disposal sites in Germany and the process of finding sites. However, international comparisons are drawn, especially to locations in the US. This affects both the repository structures and the legal requirements. The radioactive substances considered include residues from uranium ore processing, as well as low and intermediate level radioactive waste up to heat generating, high level radioactive wastes, such as spent fuel and vitrified waste from reprocessing. In order to evaluate the repository structures and their inventories, a dimensionless radiotoxicity index Ai / Fi [activity of radionuclide quantity (Ai) related to the exemption limit of radionuclide (Fi)] has been introduced. This gives the reader a well-founded overview of the degree of inconsistency in the handling of safety requirements for the respective geotechnical environmental structures. This creates the necessary transparency

on this issue, which has not been previously available and is required by stakeholders today. The long-term security, the duration of the observation period and the certainty of the safety prognosis are also discussed in the book as well as the participation of subsequent generations in current and possible future repositories. This is vital as nuclear energy will continue to be used worldwide in the long term. The international repository projects presented have all been subjected to the same evaluation criteria. This applies both to existing operational project as well as those about to be commissioned and the processes for seeking locations. Special attention has been paid to monitoring, both operational and long-term monitoring. This broad range of topics makes this book a very valuable read for both the interested public and the professional world.

Drawing on the authors' extensive experience in the processing and disposal of waste, An Introduction to Nuclear Waste Immobilisation, Second Edition examines the gamut of nuclear waste issues from the natural level of radionuclides in the environment to geological disposal of waste-forms and their long-term behavior. It covers all-important aspects of processing and immobilization, including nuclear decay, regulations, new technologies and methods. Significant focus is given to the analysis of the various matrices used, especially cement and glass, with further discussion of other matrices such as bitumen. The final chapter concentrates on the performance assessment of immobilizing materials and safety of disposal, providing a full range of the resources needed to understand and correctly immobilize nuclear waste. The fully revised second edition focuses on core technologies and has an integrated approach to immobilization and hazards Each chapter focuses on a different matrix used in nuclear waste immobilization: cement, bitumen, glass and new materials Keeps the most important issues surrounding nuclear waste - such as treatment schemes and technologies and disposal - at the forefront

With the responsibility to ensure the safety of food, drugs, and other products, the U.S. Food and Drug Administration (FDA) faces decisions that may have public-health consequences every day. Often the decisions must be made quickly and on the basis of incomplete information. FDA recognized that collecting and evaluating information on the risks posed by the regulated products in a systematic manner would aid in its decision-making process. Consequently, FDA and the Department of Health and Human Services (DHHS) asked the National Research Council (NRC) to develop a conceptual model that could evaluate products or product categories that FDA regulates and provide information on the potential health consequences associated with them. A Risk-Characterization Framework for Decision-Making at the Food and Drug Administration describes the proposed risk-characterization framework that can be used to evaluate, compare, and communicate the public-health consequences of decisions concerning a wide variety of products. The framework presented in this report is intended to complement other risk-based approaches that are in use and under development at FDA, not replace them. It provides a common language for describing potential public-health consequences of decisions, is designed to have wide applicability among all FDA centers, and draws extensively on the well-vetted risk

literature to define the relevant health dimensions for decision-making at the FDA. The report illustrates the use of that framework with several case studies, and provides conclusions and recommendations.

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Subject of the book is Uranium and its migration in aquatic environments. The following subjects are emphasised: Uranium mining, Phosphate mining, mine closure and remediation, Uranium in groundwater and in bedrock, biogeochemistry of Uranium, environmental behavior, and modeling. Particular results from the leading edge of international research are presented.

This book describes essential and effective management for reliably ensuring public safety from radioactive wastes in Japan. This is the first book to cover many aspects of wastes from the nuclear fuel cycle to research and medical use, allowing readers to understand the characterization, treatment and final disposal of generated wastes, performance assessment, institutional systems, and social issues such as intergenerational ethics. Exercises at the end of each chapter help to understand radioactive waste management in context.

Deep geological repositories are sited and designed to protect humans and the environment from the hazards associated with radioactive waste. A repository safety case needs to address the period fro which it is possible to contain the radioactivity. Furthermore, safety is usually assessed in terms of the primary indicators of dose and risk and, in order to evaluate these indicators, assumptions must be regarding rhe habits of potentially exposed groups (e.g. diet, lifestyle and land use) and these may change over timescales of just a few years. The need to deal with such a wide range fo timescales gives rise to a range of issues regarding the methods and presentation of safety assessements. The main objective of the workshop was to identify and discuss approaches related to, and work done on, the timescales issue within national radioactive waste management programmes in the context of assessing post-closure safety. The proceedings include the presentations made as well as a summary of the discussions held.

The safe disposal of the nation's nuclear waste in a geologic repository is one of the most significant and difficult scientific endeavors of the twenty-first century. Unique scientific challenges are posed by the very long-lived radioactivity of nuclear waste. Many radionuclides of vastly different chemical character must be retained by the repository for several thousand years. Some with longer half-lives, such as Pu-239 and Tc-99, need to be isolated for periods approaching a million years. In order to ensure the safety of a geologic repository, a detailed understanding of the mobility of radionuclides in complex natural systems is essential. Most of the radioactivity in a geological repository will be associated with spent nuclear fuel. In the United States spent fuel is derived from several sources. The majority is UO2 (LWR) spent fuel from commercial reactors. About 30,000 metric tons of spent fuel was in storage at commercial reactors by 1995, with the expectation that this quantity will more than double by 2010 (Integrated Data Report 1995). All spent fuel derived from commercial reactors is intended for eventual disposal in a geological repository. In addition, the DOE is the custodian of about 8000 metric tons of spent fuel, most of which is also intended for disposal in a geological repository. Although there are more than 250 types

of spent fuel in the DOE inventory, the fuels may be broadly classified into (1) uranium metal fuel, (2) aluminum-based fuel, (3) mixed oxide (MOX) fuel containing substantial plutonium, and (4) graphite fuel (Colleen Shelton-Davis, personal communications, January 2000). Disposal of spent fuel in a geological repository requires detailed knowledge of the longterm behavior of the waste forms under repository conditions, as well as the fate of radionuclides released from the waste packages as containers are breached. The proposed Yucca Mountain repository is intended to hold 70,000 metric tons of high-level nuclear waste. Nine radionuclides considered in the TSPA-VA (Total System Performance Analysis - Viability Assessment) Base Case Performance Analysis (CRWMS, 1998, cf. Table 3-14 in section 3.5.1) are of special concern because of their long half-lives, radiological toxicities, and potential mobilities under repository conditions. These are five actinide isotopes, Np-237, Pu-239, Pu-242, U-234, and Pa- 231, and four fission products, Tc-99, I-129, Se-79, and C-14. In addition, Am-241 is important because it is a parent of Np-237. An understanding of the behaviors of these elements under repository-relevant conditions is essential to safe disposal. Natural analogue studies of the mineral uraninite, UO2+x (an analogue for UO2 in spent fuel), as well as several laboratory-scale simulations, confirm that spent fuel is unstable under the moist, oxidizing conditions expected in the proposed repository at Yucca Mountain. Once containers are breached, alteration of the spent fuel m ay be rapid, with the most abundant alteration products being uranyl (U6+) phases. Shortly after groundwater or condensed water vapor contacts spent fuel in the proposed repository, uranyl phases are likely to be abundant in the vicinity of the spent fuel. Most of the uranyl phases that will form in the repository are already known as minerals from natural systems. Many of these uranyl phases can persist for thousands of years, as demonstrated by studies of natural analogues (Finch et al. 1996). It is likely that uranyl phases forming due to the alteration of spent fuel will incorporate many of the radionuclides contained in the spent fuel (Burns et al. 1997), thus having a profound impact upon the mobility of the radionuclides. Our ongoing research is leading to an understanding of the impact of incorporation of radionuclides into uranyl phases. Such information is essential to an understanding of the long-term performance of the geological repository. Knowledge of the crystal structures, chemistries, stabilities and paragenesis of uranyl minerals lag far behind most other mineral groups, owing in large part to the occurrence of these minerals as complex intergrowths of multiple phases, making routine analysis very difficult.

This book is published open access under a CC BY 4.0 license. This book summarizes presentations and discussions from the two-day international workshop held at UC Berkeley in March 2015, and derives questions to be addressed in multi-disciplinary research toward a new paradigm of nuclear safety. The consequences of the Fukushima Daiichi nuclear accident in March 2011 have fuelled the debate on nuclear safety: while there were no casualties due to radiation, there was substantial damage to local communities. The lack of common understanding of the basics of environmental and radiological sciences has made it difficult for stakeholders to develop effective strategies to accelerate recovery, and this is compounded by a lack of effective decision-making due to the eroded public trust in the government and operators. Recognizing that making a society resilient and achieving higher levels of safety relies on public participation in and feedback on decision-making, the book focuses on risk

perception and mitigation in its discussion of the development of resilient communities. Secretary of Energy, Bill Richardson, has stated that one of the nuclear waste legacy issues is "The challenge of managing the fuel cycle's back end and assuring the safe use of nuclear power." Waste management (i.e., the back end) is a domestic and international issue that must be addressed. A key tool in gaining acceptance of nuclear waste repository technologies is transparency. Transparency provides information to outside parties for independent assessment of safety, security, and legitimate use of materials. Transparency is a combination of technologies and processes that apply to all elements of the development, operation, and closure of a repository system. A test bed for nuclear repository transparency technologies has been proposed to develop a broad-based set of concepts and strategies for transparency monitoring of nuclear materials at the back end of the fuel/weapons cycle. WIPP is the world's first complete geologic repository system for nuclear materials at the back end of the cycle. While it is understood that WIPP does not currently require this type of transparency, this repository has been proposed as realistic demonstration site to generate and test ideas, methods, and technologies about what transparency may entail at the back end of the nuclear materials cycle, and which could be applicable to other international repository developments. An integrated set of transparency demonstrations was developed and deployed during the summer, and fall of 1999 as a proof-of-concept of the repository transparency technology concept. These demonstrations also provided valuable experience and insight into the implementation of future transparency technology development and application. These demonstrations included: Container Monitoring Rocky Flats to WIPP; Underground Container Monitoring; Real-Time Radiation and Environmental Monitoring; Integrated level of confidence in the system and information provided. As the world's only operating deep geologic repository, the Waste Isolation Pilot Plant (WIPP) offers a unique opportunity to serve as an international cooperative test bed for developing and demonstrating technologies and processes in a fully operational repository system setting. To address the substantial national security implications for the US resulting from the lack of integrated, transparent management and disposition of nuclear materials at the back-end of the nuclear fuel and weapons cycles, it is proposed that WIPP be used as a test bed to develop and demonstrate technologies that will enable the transparent and proliferation-resistant geologic isolation of nuclear materials. The objectives of this initiative are to: (1) enhance public confidence in safe, secure geologic isolation of nuclear materials; (2) develop, test, and demonstrate transparency measures and technologies for the back-end of nuclear fuel cycle; and (3) foster international collaborations leading to workable, effective, globally-accepted standards for the transparent monitoring of geological repositories for nuclear materials. Test-bed activities include: development and testing of monitoring measures and technologies; international demonstration experiments; transparency workshops; visiting scientist exchanges; and educational outreach.

These activities are proposed to be managed by the Department of Energy/Carlsbad Area Office (DOE/CAO) as part of The Center for Applied Repository and Underground Studies (CARUS).

Compared to other large engineering projects, geologic repositories for high-level waste present distinctive challenges because: 1) they are first-of-a-kind, complex, and long-term projects that must actively manage hazardous materials for many decades: 2) they are expected to hold these hazardous materials passively safe for many millennia after repository closure; and 3) they are widely perceived to pose serious risks. As is the case for other complex projects, repository programs should proceed in stages. One Step at a Time focuses on a management approach called "adaptive staging" as a promising means to develop geologic repositories for high-level radioactive waste such as the proposed repository at Yucca Mountain, Nevada. Adaptive staging is a learn-as-you-go process that enables project managers to continuously reevaluate and adjust the program in response to new knowledge and stakeholder input. Advice is given on how to implement staging during the construction, operation, closure, and post-closure phases of a repository program.

Coal remains an important fossil fuel resource for many nations due to its large remaining resources, relatively low production and processing cost and potential high energy intensity. Certain issues surround its utilisation, however, including emissions of pollutants and growing concern about climate change. The coal handbook: Towards cleaner production Volume 2 explores global coal use in industry. Part one is an introductory section which reviews the social and economic value of coal, emissions from coal utilisation, the handling, impact and utilisation of coal waste, and an exploration of emerging and future issues around industrial coal utilization. Chapters in part two highlight coal resources, production and use in established markets as well as the emerging markets of Brazil, the Russian Federation, India, Indonesia, and China. Part three focuses specifically on coal utilisation in industry. Chapters consider thermal coal utilisation, coal use in iron and steel metallurgy, advances in pulverised fuel technology, and the evaluation of coal for thermal and metallurgical applications. Further chapters explore coal utilisation in the cement and concrete industries, coal gasification and conversion, and value-in-use assessment for thermal and metallurgical coal. A final chapter summarises the anticipated future pathway towards sustainable, long-term coal use, suggesting transitions that will be needed to ensure cleaner utilisation for many decades to come. With its distinguished editor and international team of expert contributors, The coal handbook Volumes 1 and 2 is a comprehensive and invaluable resource for professionals in the coal mining, preparation, and utilisation industry, those in the power sector, including plant operators and engineers, and researchers and academics interested in this field. Reviews the social and economic value of coal, emissions from coal utilisation, and the handling, impact and utilisation of coal waste Explores emerging and future issues around industrial coal utilization

Highlights coal resources, production and use in established markets, as well as emerging markets such as Brazil, the Russian Federation, India, Indonesia, and China

This volume examines the national plans that ten Euratom countries plus Switzerland and the United States are developing to address high-level radioactive waste storage and disposal. The chapters, which were written by 23 international experts, outline European and national regulations, technology choices, safety criteria, monitoring systems, compensation schemes, institutional structures, and approaches to public involvement. Key stakeholders, their values and interests are introduced, the responsibilities and authority of different actors considered, decision-making processes are analyzed as well as the factors influencing different national policy choices. The views and expectations of different communities regarding participatory decision making and compensation and the steps that have been or are being taken to promote dialogue and constructive problem-solving are also considered.?

This work on science in the 20th century represents work in America, Europe and Asia. It includes such topics as the countries that have made the most significant contributions, the relationship between science and industry and the importance of instrumentation.

Geological Repository Systems for Safe Disposal of Spent Nuclear Fuels and Radioactive Waste, Second Edition, critically reviews state-of-the-art technologies and scientific methods relating to the implementation of the most effective approaches to the long-term, safe disposition of nuclear waste, also discussing regulatory developments and social engagement approaches as major themes. Chapters in Part One introduce the topic of geological disposal, providing an overview of near-surface, intermediate depth, and deep borehole disposal, spanning low-, medium- and high-level wastes. Part Two addresses the different types of repository systems - crystalline, clay, and salt, also discussing methods of site surveying and construction. The critical safety issue of engineered barrier systems is the focus of Part Three, with coverage ranging from nuclear waste canisters, to buffer and backfill materials. Lastly, Parts Four and Five focus on safety, security, and acceptability, concentrating on repository performance assessment, then radiation protection, environmental monitoring, and social engagement. Comprehensively revised, updated, and expanded with 25% new material on topics of current importance, this is the standard reference for all nuclear waste management and geological repository professionals and researchers. Contains 25% more material on topics of current importance in this new, comprehensive edition Fully updated coverage of both near-surface/intermediate depth, and deep borehole disposal in one convenient volume Goes beyond the scientific and technical aspects of disposal to include the political, regulatory, and societal issues involved, all from an international perspective

It is internationally accepted that the safest and most sustainable option for

managing radioactive waste is geological disposal, utilizing both engineering and geology to isolate the waste and contain the radioactivity. This Special Publication contains 25 scientific studies presented at the 6th conference on ‘Clays in natural and engineered barriers for radioactive waste confinement’ held in Brussels, Belgium in 2015. The conference and this resulting volume cover many of the aspects of clay characterization and behaviour considered at various temporal and spatial scales relevant to the confinement of radionuclides in clay, from basic phenomenological process descriptions to the global understanding of performance and safety at repository and geological scales. The papers in this volume consider research into argillaceous media under the following topic areas: large-scale geological characterization; general strategy for clay-based disposal systems; geomechanics; mass transfer; bentonite evolution and gas transfer. The collection of different topics presented in this Special Publication demonstrates the diversity of geological repository research.
Solubility is fundamental to most areas of chemistry and is one of the most basic of thermodynamic properties. It underlies most industrial processes. Bringing together the latest developments and ideas, Developments and Applications in Solubility covers many varied and disparate topics. The book is a collection of work from leading experts in their fields and covers the theory of solubility, modelling and simulation, industrial applications and new data and recent developments relating to solubility. Of particular interest are sections on: experimental, calculated and predicted solubilities; solubility phenomena in 'green' quaternary mixtures involving ionic liquids; molecular simulation approaches to solubility; solubility impurities in cryogenic liquids and carbon dioxide in chemical processes. The book is a definitive and comprehensive reference to what is new in solubility and is ideal for researcher scientists, industrialists and academics
Many countries are currently exploring the option to dispose of highly radioactive solid wastes deep underground in purpose built, engineered repositories. A number of surface and shallow repositories for less radioactive wastes are already in operation. One of the challenges facing the nuclear industry is to demonstrate confidently that a repository will contain wastes for so long that any releases that might take place in the future will pose no significant health or environmental risk. One method for building confidence in the long-term future safety of a repository is to look at the physical and chemical processes which operate in natural and archaeological systems, and to draw appropriate parallels with the repository. For example, to understand why some uranium orebodies have remained isolated underground for billions of years. Such studies are called 'natural analogues'. This book investigates the concept of geological disposal and examines the wide range of natural analogues which have been studied. Lessons learnt from studies of archaeological and natural systems can be used to improve our capabilities for assessing the future safety of a radioactive waste repository.
Damaged fuels originated from the accident at the Fukushima-Daiichi Nuclear

Power Station, and the spent nuclear fuels from commercial light water reactors (LWRs) in Japan are considered to be disposed of in deep geological repository. For a prospective repository, as part of generic performance assessment, a criticality safety assessment (CSA) should be performed to ensure that the repository system including the engineered barriers and host geological formations remains sub-critical for tens of thousands to millions of years. For various repository concepts, CSA is considered to include three major stages in chronological order: (1) the stage before package failure, (2) the stage after package failure, while fissile nuclides remain within the engineered barrier system (EBS) and in the near-field region, and (3) the stage in which fissile nuclides originated from multiple packages are deposited in far-field host rocks. Defining the model for neutronics calculations plays a central role in CSAs, where conservative assumptions are usually made to cope with various uncertainties and to simplify the model. The aim of this dissertation is to develop neutronics models for different stages in the criticality safety study, and provide basic understandings for the long-term criticality safety for the disposal of spent nuclear fuel in geologic repository. In the near-field analysis, a neutronics model has been developed for a system consisting of a canister containing fuel debris from Fukushima reactors and the surrounding buffer, in a water-saturated deep geological repository. The fuel debris has been modeled as a hexagonal lattice of spherical fuel particles. Following key observations have been concluded from the numerical results: (a) the calculated neutron multiplicity (keff) is sensitively dependent on assumptions related to moderation, (b) the carbon steel canister plays an important role in reducing the potential for criticality, (c) the maximum keff of the canister-buffer system could be achieved after a fraction of fissile nuclides been released from the canister, and (d) under several assumptions, the maximum keff of the canister-buffer system could be principally determined by the dimension and composition of the canister, not by the initial fuel loading. Based on the preliminary results and findings, a parametric study has been made to identify the optimized lattice parameters for criticality. And the critical mass of damaged fuels for a single canister has been calculated. If this critical mass is used as the maximum canister mass loadings, roughly a thousand canisters are needed to contain the damaged fuels from the three damaged cores. For the LWR spent fuels, a parametric study has been performed to examine spent fuels with different designs and burnup histories. The numerical results indicate that, under the conditions assumed, for all UO2 spent fuels and most of the MOX spent fuels, the single canister model will always be subcritical. The far-field study has been focusing on neutronic analysis to examine the criticality conditions for uranium depositions in geological formations which result from geological disposal of damaged fuels from Fukushima reactors. Neutronics models are used to evaluate the keff and critical mass for various combinations of host rock and geometries. The present study has revealed that the planar fracture geometry applied in the previous criticality safety assessment for

geological disposal would not necessarily yield conservative results against the homogeneous uranium deposition. It has been found that various far-field critical configurations are conceivable for given conditions of materials and geological formations. Prior to knowing the site location, some important points for selecting a site for criticality safety can be suggested. These include: (a) iron existing in the host rock reduces the likelihood of criticality significantly; (b) low host rock porosity is preferred for criticality safety; (c) the conservatism could change when comparing heterogeneous geometries for different fracture apertures; and (d) the importance of the mass of the deposition increases when it is smaller. As part of the improvement for the models developed in the far-field analysis, preliminary works on uranium depositions in randomly fractured rocks have been presented. The randomly fractured geometry could fundamentally influence the far-field criticality, because the system's keff value sensitively depends on the fracture aperture and the depositions at fracture intersections. No previous work has been made to study the effect of random geometry in the context of the long-term criticality safety in a geologic repository. Different numerical schemes have been developed and compared for the direct sampling of uranium depositions in randomly fractured rocks using MCNP. A general literature review of existing methods for neutron transport problems with random processes has been made. And the analytical Feinberg-Galanin-Horning (FGH) method has been derived and tested for a numerical example.