MANAGING VERY LONG-TERM STORAGE AND
THE DISPOSAL OF SPENT FUEL

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EXPERIENCE IN ANALYZING SAFETY OF SNF MANAGEMENT BACK-END IN THE RUSSIAN FEDERATION

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Abstract

The safety of SNF management back end regardless the strategy (processing, direct disposal) requires reliable data on the behavior of high-level long-lived radionuclides in geological media. Safety justification for radionuclide disposal facilities implies the use of robust models describing a) radionuclide propagation in complex media with special properties defined by the geological environment as well as b) all the processes which are significant in terms of possible mechanisms that determine the characteristics of radionuclide migration. This paper provides a brief summary of the known research in Russia on groundwater radionuclide migration models and an overview of methodological tool used by IBRAE RAS to address the forecast of radionuclide migration in the geological environment, based on different types of conducting medium representation and methods for water-rock interaction. Structural peculiarities, which may lead to non-classical radionuclide transport modes in geological media, are identified. A number of physical models reflecting these peculiarities and demonstrating anomalous transport behavior are discussed. Special attention is paid to asymptotical behavior of the contaminant concentration at large distances from the source.

1. INTRODUCTION

The lack of unanimity on the implementation of SNF management back end results from significant uncertainties in assessing the prospects for nuclear power industry. This uncertainty concerns setting the deadline of national nuclear programs, adoption and implementation of new development programs including those focused on closed nuclear fuel cycle. In practice, the strategy of deferred decision is implemented when optional prospect of SNF direct disposal or processing is declared. Similar situation is typical for Russia. The declared strategic goal (transition to closed fuel cycle) does not envisage significant increase of fuel processing capacities until the scope of a new technological platform to be the basis for the next generation nuclear power industry is determined.

In any case, while implementing the strategy of SNF reprocessing or SNF direct disposal, safe disposal of high level waste (HLW) requires the solution of complex scientific problems related to justification of disposal facility safety for the population and the environment for a period of several millennia. The urgency of these tasks will increase substantially in the coming years due to the changes in national policy on radioactive waste management and creation of repositories for RadW various categories.

The paper is structured as follows: section 2 is devoted to the Russian experience in numerical modeling of groundwater flow and radionuclide transport and the plans of IBRAE in this area; section 3 presents the advances in non-classical radionuclide transport physical models; brief conclusions are made in section 4.

2. EXPERIENCE IN GROUNDWATER FLOW AND TRANSPORT MODELING

With regard to modeling radionuclide migration in groundwater IBRAE RAS focuses on two main areas: numerical and mathematical models. Numerical models are the main tool to make sound long-term (up to million years) forecasts of contaminant propagation in the groundwater. Numerical models differ in dimension (1D, 2D, 3D), type of conducting medium representation (porous or fractured) and extent to which physical effects are taken into account. The main physical processes reflected in the models are one- or two-phase (water-air) groundwater flow based on the Darcy's law, advection and dispersion. The effects of molecular diffusion, sorption, radioactive decay, heat transfer, chemical and biological transformations are taken into account optionally.

Porous media models are suitable to describe the processes occurring in plastic and loose/granular media for which fracturing is not typical. For example, their use is appropriate for waste disposal in clay layers or transportation in sand layers. On the contrary fractured medium models are suitable for modeling processes in rock massifs which have very low intrinsic rock permeability and the transfer is carried out through the fractures. Models of the second type either use direct simulation of individual fractures or are reduced to the first type model through upscaling and use of dual porosity and dual permeability concepts.

Presently, to the best of our knowledge, the following works in the area of numerical hydrogeological modeling performed by Russian scientific institutions are known:

- Institute of Geoecology RAS (St. Petersburg branch): experience in using large number of commercial products. Calculations of radionuclide migration (the Karachay lake), survey at Leningrad Radon Special Combine site(Lenspetskombinat) in Sosnovy Bor;
- GEON-3D regional model of JSC "GeoSpetsEkologiya" which is specifically developed for the calculation of groundwater flow and radionuclide transport at PA "Mayak" site and its surroundings. This two-dimensional model with local three-dimensional zooms uses porous conducting medium approach;
- Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (IGEM RAS): experience in modeling radionuclide distribution in deep aquifers (injection of liquid radioactive waste into the aquifer at Mining and Chemical Combine). Two-dimensional models for the porous medium have been developed. The experience in conducting media classification and selection of adequate models has been accumulated;
- RFNC-VNIIEF: "Nympha" software package which includes GIS, databases, visualization means and three-dimensional calculation model (porous medium approach);
- VNIPI Promtehnologii (VNIPIPT) research to prepare input data for assessment of hydrogeological parameters of the possible locations for construction of deep storage facilities for long-lived radioactive waste at the Krasnoyarsk Territory. Simulation was performed under the joint project implemented in cooperation with German organizations (GRS, BGR, DBEtec) using FEFLOW commercial software complex;
- Geological Faculty of the Moscow State University, Department of Hydrogeology: development of stochastic models (Techa Cascade and other facilities), models of migration in fractured carbonate media and geochemical models;
- Research Institute NII VODGEO and RSC "Kurchatov Institute"; development of groundwater flow and mass transfer models for the radioactive waste storage facilities located at the territory of RSC "Kurchatov Institute" and Ulba Metallurgical Plant (Kazakhstan). Modeling included field and laboratory works, development of GIS and numerical simulation using MODFLOW (U.S. Geological Survey) and MT3DMS (The University of Alabama) software with the assessment of sensitivity to input parameters.

In our opinion, Russia has accumulated significant experience in building models for particular problems of radiation safety, but there is no systematic approach to software development to address subsurface flow and radionuclide migration. IBRAE RAS has reviewed the existing models and is making efforts to create such software package and verify it at the specific nuclear and radiation hazardous facilities. In the next three years the following activities are planned:

(1) Formalization of the process for constructing hydrogeological models and making calculations of safety parameters;
(2) Systematization of existing knowledge and software for porous media models (clay, sand), adaptation of the developed codes for the upcoming tasks (1–1.5 years is required);
(3) Development of the software for modeling processes in fractured media;
(4) Cooperation with institutions having experience of work at specific facilities. For example, cooperation with the Institute of Geoecology RAS (St. Petersburg branch) for the projects in Sosnovy Bor, cooperation with VNIPIPT for the projects at Mining and Chemical Combine.

Computational technologies are developed in parallel with their verification and application at specific sites to address actual problems of the facilities under real conditions (for example, availability of the experimental data). The main features expected from emerging computational technologies are:

- Integrated description and forecasting of the processes of saturated-unsaturated groundwater flow, advection and diffusion in fractured porous media, sorption, heat transfer and possibly chemical and biological transformations;
- Use of three-dimensional grids with mixed cell types (hexahedra, tetrahedra, prisms, pyramids);
- Interaction with GIS;
- Application of modern numerical methods for discretization, featuring high order of accuracy and robustness with respect to media heterogeneity and anisotropy;
- Efficient methods to address nonlinear systems (inexact Newton method) and linear systems (Krylov subspace iterative methods);
- Ability to make calculations for a long period of time (up to million of years);
- Availability of model calibration means;
- Ability to make calculations on supercomputers.

To perform the assessment of the reliability of radioactive waste disposal, adequate methods to describe radionuclide migration in geological media should be available. An extensive amount of field observations accumulated in the last decades evidences that in many cases classical regularities cannot describe contaminant transport processes in geological media so that discrepancies may be of several orders [1]. In this connection, at IBRAE RAS the research was undertaken to describe anomalous contaminant transport in highly heterogeneous media as applied to the radioactive waste problem. Some results of this study are presented hereafter.

1. NON-CLASSICAL TRANSPORT PROCESSES IN GEOLOGICAL MEDIA: BASIC PHYSICAL MODELS

2.1. Main factors determining anomalous transport in fractured media

One of the key factors determining moisture seepage and contaminant transport in geological media is the geometry of the fracture systems. Such systems as a rule can be classified as percolation media. Characteristics of them are determined by the connectivity property of their structural elements. Such elements are combined into clusters inside of which moisture migration and solute transport are effective, while between separate clusters these processes are weak. Two characteristics of percolation media are most important. The first one is the existence of a percolation threshold. Below the threshold, there are only finite clusters, and stationary processes of moisture infiltration in the infinite medium are ineffective. Above the percolation threshold, the medium contains an infinite cluster and the transport is not limited with respect to spatial range. The second characteristic of percolation media is the correlation length ξ. Below the percolation threshold, cluster sizes l are in the range $l < \xi$ (the number of clusters with length scale $l >> \xi$ is exponentially small). In this case, each individual cluster in the scale interval from a certain a, which we call the lower truncation size, to the dimension of the cluster itself has fractal properties [2]. This means that the cluster as a geometric object has not integral but fractal space dimension. On approaching the percolation threshold, the correlation length tends to infinity, $\xi \to \infty$, and an infinite cluster arises in the medium. Above the percolation threshold the parameter ξ becomes finite again. The percolation medium in this state is fractal at scales $a < l < \xi$, and is statistically homogeneous at scales $l >> \xi$.

A basic mechanism of tracer transport in fracture rocks is through advection during moisture seepage. Percolation systems of fractures tend to be highly disordered, making solute advection a random process. Because of the fractal nature of percolation clusters, correlations of the advection velocity are long-ranged (decaying according to a power law). Due to this factor and because advection is a rather fast transport mechanism, it may provide a **super-diffusive** transport regime [1] with $\gamma > 1/2$ in the relation

$$R(t) \propto t^{\gamma} \qquad (0)$$

for the dependence of contaminant plume size on time (remind that $\gamma = 1/2$ corresponds to classical diffusion).

Another important aspect for transport processes in geological media arises from sharply contrasting properties, caused by the presence of a low-permeable matrix. For solute transport through fractures containing moisture, the matrix plays the role of traps and ultimately gives rise to slowing down infiltration and solute transport. Along with this, a percolation cluster has a complicated topological structure, consisting of a backbone and a set of dead ends. The backbone connects remote parts of the cluster, whereas dead ends are connected with the backbone at only one point, remaining isolated from each other and from other domains of the backbone. Therefore, with respect to infiltration and transport processes, dead ends also play the role of traps. They together with the matrix may be considered as a low-permeable subsystem of the fractured geological medium, in contrast to the connected fractures of the backbone, which form a high-permeable subsystem.

With regard to the existence of two contrasting subsystem, all tracer particles may be subdivided into two parts: “active particles,” which are those in the high-permeable subsystem, and "passive particles," which reside in the low-permeable subsystem. Of primary interest are the active particles because of their high effective mobility. The presence of a low-permeable subsystem has two important consequences. The first one is that the number of active particles will decrease over time, as some of them become trapped. The second consequence of the presence of a low-permeable subsystem is to slow down solute transport, promoting a **sub-diffusive** transport mode [1] with $\gamma < 1/2$ in Eq. (1).

One more important factor forming transport processes in geological media is the strong fluctuations of the moisture seepage characteristics [1]. They arise because of the random structure of geological media. The evolution of solute concentrations in space and time depends on the specific location of the initial solute concentration distribution (source region). Therefore, spatial fluctuations of medium characteristics may effectively renormalize the solute source power.

Further we present a number of physical models to describe nonclassical contaminant transport in geological media taking into account above listed factors.

2.2. Random advection with infinite correlation length ($\xi \to \infty$)

A basis of the model is the equation for particles concentration $c(\vec{r},t)$

$$\frac{\partial c}{\partial t} + \nabla(\vec{v}c) = 0 \tag{2}$$

The volumetric moisture flux $\vec{v}(\vec{r})$ is a random function of coordinates obeying incompressibility equation $div\,\vec{v} = 0$ and the condition $<\vec{v}(\vec{r})>=0$, where $<\cdots>$ is the average over an ensemble of realizations. Flux correlations at large distances decrease according to power law and the n- point correlation function defined by the equality $K_{i_1 i_2 \ldots i_n}(\vec{r}_1,\vec{r}_2 \ldots \vec{r}_n) =< v_{i_1}(\vec{r}_1) v_{i_2}(\vec{r}_2) \ldots v_{i_n}(\vec{r}_n)>$ is uniform function of the order $-nh$ at $|\vec{r}_i - \vec{r}_j| >> a$ (for all pairs of $\vec{r}_i$, $\vec{r}_j$), where $h>0$ and a is a short-range truncation radius. In particular, for the pair correlation function we have

$$K_{ij}(\vec{r}_1-\vec{r}_2) \equiv < v_i(\vec{r}_1) v_j(\vec{r}_2) > \cong V^2 \left(a/|\vec{r}_1-\vec{r}_2|\right)^{2h}, \tag{3}$$

where V is the characteristic value of $K_{ij}(\vec{r}_1-\vec{r}_2)$ at $|\vec{r}_1-\vec{r}_2| < a$.

The main results of the analysis of the random advection model [3, 4] consist in the following. At $h>1$ contaminant transport corresponds to classical diffusion with diffusivity $D \sim Va$. At $h<1$ the contaminant concentration averaged over an ensemble of medium realization $\overline{c}(\vec{r},t) \equiv < \overline{c}(\vec{r},t) >$ is determined as

$$\overline{c}(\vec{r},t) = NR^{-3}(t)\Phi(\zeta), \quad \zeta = r/R(t) \tag{4}$$

Here $\Phi(0) \sim 1$ and $\Phi(\zeta) \to 0$ for $\zeta \to \infty$; N is the total number of contaminant particles.

The quantity $R(t)$, defined as

$$R(t) = \left(a^h V t\right)^{\gamma} \qquad with \qquad \gamma = (1+h)^{-1}, \tag{5}$$

determines the contaminant plume size at time t. Since $\gamma > 1/2$ for $h<1$, the transport regime under this condition corresponds to the super-diffusion mode.

The asymptotic behavior of concentration at large distances is:

$$\bar{c}\left(\vec{r},t\right) \propto \exp\left(-A\,\zeta^{(1+h)/h}\right), \quad A \sim 1 \qquad at \quad r >> R\left(t\right). \tag{6}$$

Note that $\left(1+h\right)/h > 2$ in the exponent of Eq. (6) at $h < 1$. Therefore the concentration decay in the super-diffusion regime of random advection model is of contracted exponential type and is even faster than the Gaussian one in classical diffusion (see Fig. 1). This is in sharp contrast to fractional diffusion (formally mathematical model based on fractional spatial derivatives), whose tails are of the power-law type.

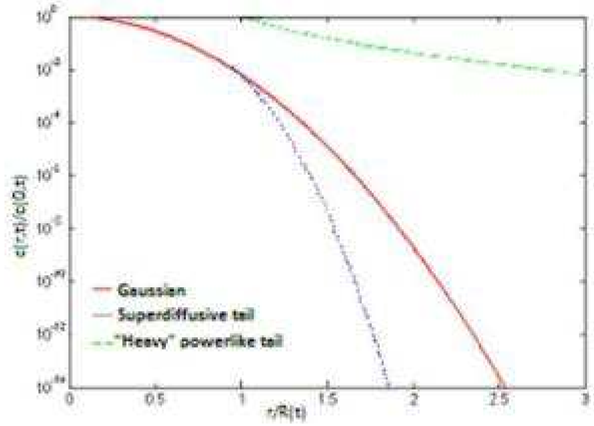

FIG. 1. Gaussian (classical), super-diffusive and "heavy" power-like concentration tails.

2.3. Random advection with finite correlation length ($\xi < \infty$)

Under the condition of finite correlation length the advection velocity may be represented in the form

$$\vec{v}\left(\vec{r}\right) = \vec{u} + \vec{v}'\left(\vec{r}\right), \tag{7}$$

where $\vec{u} = < \vec{v}\left(\vec{r}\right) >$. The correlation function of the "random" term $\vec{v}'\left(\vec{r}\right)$ possesses the properties of Eq. (2), which are now valid only at $a << \left|\vec{r}_1 - \vec{r}_2\right| << \xi$. All correlations decay at $\left|\vec{r}_i - \vec{r}_j\right| > \xi$ exponentially fast. The main results of the analysis of this model [4, 5] are as follows.

At short times, $t < t_\xi$, where $t_\xi = \xi / u \approx \xi^{1+h} / a^h V$, in the case of $h < 1$, the results reduce to random advection with infinite correlation length (see previous section). At long times, when $t > t_\xi$, the classical diffusive regime is realized:

$$\bar{c}\left(\vec{r},t\right) = N\left(4\pi D_{eff}t\right)^{-3/2} \exp\left(-\left(\vec{r}-\vec{u}t\right)^2 / 4D_{eff}t\right) \qquad with \quad D_{eff} \sim u\xi\,. \tag{8}$$

This expression is valid at $\left|\vec{r}-\vec{u}t\right| << ut$.

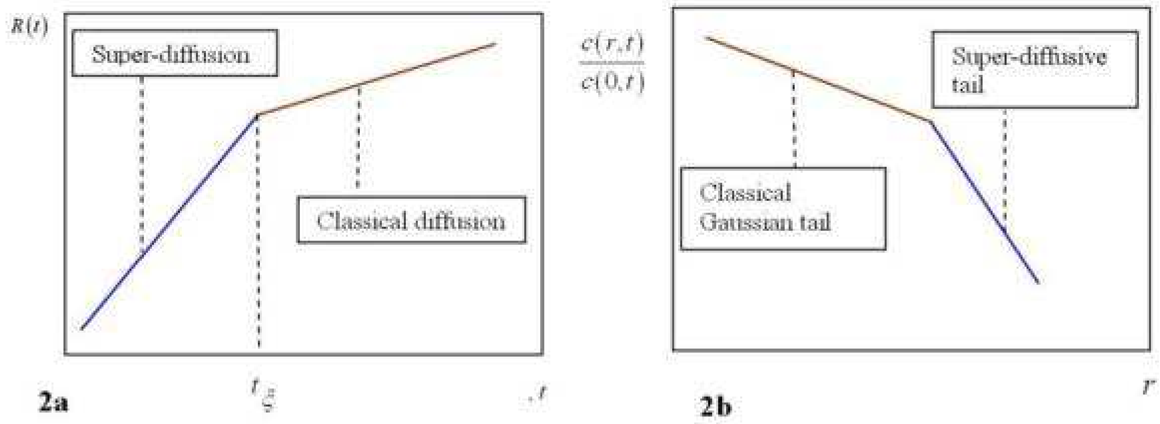

FIG. 2. Contaminant plume size $h<1$ (2a) and two-stage concentration tail at $t>t_\xi$ (2b)

At large distances $|\vec{r}-\vec{u}t| >> ut$, the concentration behavior is described by the asymptotic expression (6), which also provides the concentration asymptotics at short times for $h<1$.

Therefore, in the case of finite correlation length, $\xi<\infty$, the concentration tail at $t>t_\xi$ has a two-stage structure. The near stage is the classical one, while the far-tail stage corresponds to superdiffusive asymptotics. The transition between the two stages of asymptotics occurs when

$$\bar{c} \propto \exp\left(-At/t_\xi\right) \quad \textit{with} \quad A\sim 1. \tag{9}$$

Contaminant plume size at $h<1$ and two-stage concentration tail at $t>t_\xi$ are represented schematically in Fig. 2.

2.4. Contaminant transport over percolation media with classical diffusion as physical mechanism

Basing on the considerations of Section 3.1, the equation for the concentration of active particles averaged over an ensemble of realizations of the medium can be written as

$$\frac{\partial \bar{c}(\vec{r},t)}{\partial t} + \int_{-\infty}^{t} dt' \varphi(t-t')\bar{c}(\vec{r},t') = D\Delta\bar{c}(\vec{r},t), \tag{10}$$

where D is the bare diffusivity. The kernel $\varphi(t-t')$ has the properties

$$\varphi(t) \sim t_a^{-2}(t_a/t)^{1+\alpha} \quad \textit{with} \quad 0<\alpha<1 \qquad \textit{at} \quad t_a << t << t_\xi, \tag{11}$$

$\varphi(t)\sim 1/t_a^2$ at $t\le t_a$, and $\varphi(t)$ decays exponentially at $t>t_\xi$. Characteristic times t_a and t_ξ are determined by the relations

$$t_a \sim a^2/D, \qquad t_\xi \sim t_a(\xi/a)^{\frac{2}{\alpha}} \tag{12}$$

As before, a is the lower truncation size and ξ the correlation length.
In this model, transport regimes and concentration asymptotics for the medium state above the percolation threshold consist in the following [6].

In the interval $t_a << t << t_\xi$, the transport goes in the sub-diffusive regime with contaminant plume size given by the relation

$$R(t) \sim a\left(t / t_a\right)^{\alpha/2}. \tag{13}$$

The total number of active particles (residing in the back-bone of percolation cluster) decays with time as

$$N(t) \sim N(0)\left(t_a / t\right)^{1-\alpha}. \tag{14}$$

In this regime, the asymptotic behavior of concentration at large distances is determined by

$$\bar{c}(\vec{r},t) \propto \exp\left(-B\eta^{2/(2-\alpha)}\right) \quad \eta = r / R(t) \quad B \sim 1. \tag{15}$$

Note that the concentration decay in the sub-diffusion regime is slower than the Gaussian one in classical diffusion.

At times $t >> t_\xi$ the active particle concentration obeys the classical diffusion equation with the renormalized diffusivity $\tilde{D}$:

$$\bar{c}(\vec{r},t) \cong N_\infty \left(4\pi\tilde{D}t\right)^{-3/2} \exp\left(-r^2 / 4\tilde{D}t\right) \tag{16}$$

The total number of active particles at these times remains to be constant, $N(t) \cong N_\infty$. The renormalization factors for the diffusion coefficient and the total number of active particles are equal:

$$\tilde{D} / D = N_\infty / N(0) = F, \qquad F \sim \left(a / \xi\right)^{2(1-\alpha)/\alpha}. \tag{17}$$

The expression (17) is valid at the distances $r < \sqrt{4\tilde{D}t^2 / t_\xi}$. At the more remote distances when $r > \sqrt{4\tilde{D}t^2 / t_\xi}$, the classical Gaussian tail described by Eq. (16) changes with the sub-diffusive tail of Eq. (15). So the concentration asymptotics at $t >> t_\xi$ has the multistage structure.

2.5. Renormalization of contaminant source power due to fluctuation effects

Under the condition when the contaminant source surface area S is comparable to the square of the lower truncation size ($S \sim a^2$), the strong fluctuations of the medium properties renormalize the source power [7]. The renormalization factor K is determined by rare combinations of favorable conditions — “leakage path“ (punctures). This situation resembles the problem of tunneling barrier in semiconductors explored in [8], and so we take advantage the approach of this work. Like [8], the distribution of the puncture concentrations per unit area of the source boundary can be expressed as

$$\rho(u) = (S_0)^{-1} \, exp[-\Omega(u)] \tag{18}$$

where S_0 is the characteristic cross-sectional size of the puncture, which is small compared to the average distance between punctures, u is an auxiliary variable running the values from 0 to $+\infty$, and $\Omega(u)$ is a function having the properties $\Omega(u) >> 1$, $\partial\Omega/\partial u < 0$, $\partial^2\Omega/\partial u^2 > 0$.

The analysis [4, 7] using an averaging procedure over the puncture concentration distribution leads to the following results. For large source sizes, $S > a^2$, the renormalizing factor is close to unity. At small source sizes, the renormalizing factor rapidly decreases with S

$$K \propto exp\left[-\left(u_f - u_{opt}\right)\right] \quad \text{at} \quad S << a^2 \tag{19}$$

where the quantities u_{opt} and u_f are determined by the equations $\left(\partial\Omega(u)/\partial u\right)_{u=u_{opt}} + 1 = 0$ and $\left(S/S_0\right)\exp\left[-\Omega\left(u_f\right)\right] = 1$. Note that we have $K << 1$ at $S << a^2$.

One additional effect caused by the fluctuations concerns the statistical scatter of the renormalization factor K. The relative scatter $\Delta(K) \equiv < (K - < K >)^2 > / < K >$ is small at large source sizes and becomes large at small source sizes.

3. CONCLUSIONS

The analysis of Russian experience in groundwater flow and radionuclide transport modeling shows that there is ongoing and already conducted research on a couple of sites. At the same time we see the necessity in a systematic approach to the nuclear safety assessment and the development of a unified methodology and computational technologies to address radionuclide migration in the subsurface.

Four physical models presented in this paper manifest main features of geological media giving rise to non-classical contaminant transport. These are fractal geometry of fractures, advection flows as dominating transport physical mechanism, sharp contrast in property distribution, and spatial fluctuations of the medium characteristics. The contaminant concentration at large distances (in tail) decays exponentially in both super- and sub-diffusive transport modes. The change of transport regimes with time results in a multistage structure of concentration tails. With increasing distance from the source at a fixed time, concentration asymptotics reproduce the transport regimes in inverse time order. Spatial fluctuations of medium properties can lead to a significant renormalization of the contaminant source power.

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DEVELOPING THE TECHNICAL DATA SUPPORTING LICENSING OF VERY LONG TERM DRY STORAGE OF SPENT NUCLEAR FUEL

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Abstract

At the last meeting of this series in 2006, license renewal and long-term storage were identified as topics that needed further consideration in the near future. Since that time three independent actions took place: 1) In June 2009 the Nuclear Waste Technical Review Board, conducted a public meeting to review the information available to provide a sound regulatory and technical basis for the safe and secure long-term storage of spent nuclear fuel (SNF), 2) On February 18, 2010, the Commissioners of the United States Nuclear Regulatory Commission (NRC) directed the NRC staff to undertake a thorough review of the regulatory programs for spent fuel storage and transportation, including their adequacy for ensuring safe and secure storage and transportation of spent fuel for extended periods beyond the 120-year timeframe considered up to this point. [1], and 3) On March 3, 2010, the US Department of Energy (DOE) motioned to withdraw its pending license application for Yucca Mountain as a permanent site for disposal of SNF. This action could lead to a need for very long-term dry storage (VLTDS) of spent nuclear fuel (SNF). All of the above suggest a need for better technical data to support the safe and secure storage of SNF for a long time and to be able to remain in a transportable condition without repackaging. To date, the staff of the Spent Fuel Storage and Transportation Division (SFST) of the NRC has observed no data or operating experience that indicates that SNF cannot be safely and securely stored for a very long term and remain in a transportable configuration in large casks under the proper storage conditions with an appropriate aging management plan. However, the staff currently believes that additional data is necessary to confirm and to demonstrate that VLTDS and subsequent transportation, without repackaging, can be safely accomplished. To address this potential need, the SFST staff is developing a plan for Commission approval to address both the regulatory and technical requirements. The plan calls for four tasks: 1) identification of additional data needs in the available technical information supporting long-term storage of SNF, if any, 2) performance of short term research to address the identified needs, 3) evaluation of the current regulatory framework, and 4) performance of a well-monitored long-term demonstration that uses high burnup fuel (HBU) (i.e. >45 GWD/MTU). This paper will discuss the development of this plan.

1. INTRODUCTION

1.1. Background to the back-end of the fuel cycle

On 3 March 2010, the US DOE motioned to withdraw its pending license application for Yucca Mountain as a permanent site for disposal of SNF. In addition, the U.S. Secretary of Energy has formed a Blue Ribbon Panel to evaluate other potential paths to handle SNF. These may include, but are not limited to: 1) other repository sites, 2) reprocessing of commercial fuel as is the practice in some other countries, 3) development of new reprocessing methods with their own unique waste forms such as pyroprocessing, 4) other types of disposal such as sub-seabed, or 5) novel approaches to the issue of handling waste. The time frame to develop any of these options in the United States will likely result in the need for VLTDS of SNF, while maintaining the ability to subsequently transport the fuel to a final destination in large casks.

The uncertainty in developing a long-term disposal solution can lead to public concerns about the use of nuclear energy. On 18 February 2010, the Commissioners of the United States Nuclear Regulatory Commission (NRC) directed the staff of the NRC to undertake a thorough review of the regulatory programs for spent fuel storage and transportation in order to evaluate their adequacy for ensuring safe and secure storage and transportation of spent fuel for extended periods beyond the 120-year timeframe considered up to this point [1]. In addition, the Nuclear Waste Technical Review Board (NWTRB) conducted a public meeting in June 2009, to review information available to provide a sound regulatory and technical basis for the long-term storage of SNF [2]. These three independent drivers indicate a need to evaluate the regulatory and technical basis supporting VLTDS of SNF.

1.2. Current situation

Storage of SNF was initially licensed for a 20 year period under 10 CFR Part 72. Some sites have applied for and been granted extended licenses for an additional 40 year period. In addition, the decisions to extend the licenses were influenced by the results of an examination of lower burnup (~30 GWd/MTU) fuel stored dry at the Idaho National Laboratory (INL) [3], and the institution of an aging management plan [4]. The Idaho study demonstrated that no degradation of the stored fuel or internal components of the dry storage cask occurred. Recently the Commission has approved and submitted for public comment a proposed amendment to 10 CFR Part 72 to increase the initial and subsequent terms of storage to 40 years. A standard review plan (NUREG-1927) for license renewal [4] was also issued for public comment. Based on the INL test data, industry experience to date, and implementation of an effective aging management program, the NRC determined that there is reasonable confidence that low burnup fuel can be stored for very long periods of time and then transported. However the existing test INL data may not be representative of how high burnup (HBU) fuel (burnup > 45 GWd/MTU) behaves. HBU fuel has been in storage for only a short period of time, and as a result, other than extrapolative calculations, there is no data available to support its integrity during transportation after periods of VLTDS. In addition, no high burnup fuel has been transported in a large rail package to give direct evidence that it can be done without disrupting the condition of the fuel. In all probability, and if necessary, HBU fuel could be shipped in small packages.

Currently SNF in the United States is licensed for storage under 10 CFR Part 72 [5] and certified for transportation under 10 CFR Part71 [6]. These licenses can be obtained independently, and often are, for systems that are deemed dual purpose. While there are similarities in the technical acceptance criteria, there is no guarantee that obtaining a storage certificate will allow the certificate holder to obtain a transportation certificate, which can lead to regulatory uncertainty whether SNF licensed for storage can be licensed for transport in large packages.

1.3. Programmatic goals

Because the path forward for the back end of the fuel cycle appears to be evolving, and most options will require VLTDS, the Division of Spent Fuel Storage and Transportation developed a plan to establish a technical basis and regulatory infrastructure to support the potential options that might arise. The goals of this program are to:

- Streamline the storage and transportation regulatory process;
- Identify issues related to VLTDS of SNF that may require rulemaking or guidance changes early so they can be evaluated and corrected;
- Provide for early identification and disposition of potential unforeseen long-term issues, and in confirming the validity of the technical basis for VLTDS to support the regulatory approach.

2. PROGRAMMATIC ASSUMPTIONS

To meet the goals stated above a number of assumptions were made in developing the plan to support VLTDS. The plan is flexible to adjust to technical or policy changes. The assumptions made in establishing this initial program are:

(1) Currently, 10 CFR 72 requires retrievability of SNF but 10 CFR 71 does not. Since the final disposition of the fuel has not been determined, it is assumed that the fuel should be maintained in storage and under subsequent transport in essentially the same condition it was placed into storage;
(2) Only uranium-oxide based SNF (UOX) fuel, mixed oxide (MOX) fuel, and gas-cooled reactor graphite fuel [i.e. Fort St Vrain (FSV)] are initially considered. The UOX fuel comprises the bulk of the commercial fuel currently in storage and the fuel that will be placed in storage in the near future in the United States. The characteristics of MOX fuel are very similar to UOX fuel. The FSV fuel is currently in storage under an NRC license and will eventually have to be transported;
(3) Research reactor SNF (DOESNF) is not considered in the current plan. Currently the storage of DOESNF falls under the auspices of the U.S. Department of Energy (DOE). These forms will eventually be transported under NRC auspices;
(4) Only current modes of storage and transportation (Concrete or metal over packs, above and below ground) are being considered;
(5) The current licensed fuel burnup limits in-reactor will not be increased without confirming that fuel can be safely handled and considering the impact of raising the burnup limit on the back-end of the fuel cycle;
(6) Long-term institutional controls will be maintained.

3. PLAN TO OBTAIN TECHNICAL DATA TO SUPPORT VLTDS AND SUBSEQUENT TRANSPORTATION

The overall plan is to establish a technically supportable regulatory process for the safe and secure VLTDS and subsequent transportation of SNF. Elements of the program include:

- Re-evaluate current regulatory practices for storage and transportation to make them more efficient and address both long and short term issues;
- Re-evaluate previous assessments of the viability of VLTDS. This includes review of all pertinent documentation and possible expert elicitation;
- Develop and conduct a series of short-term research projects addressing the concerns identified in the analysis;
- Develop and conduct a long-term cask demonstration, and a long-term monitoring program, using high burnup fuel, to collect fuel performance data, identify any unforeseen degradation, validate short term conclusions over the long-term, and efficiently manage any problems that might occur. While any short-term program provides an indication that extrapolations can be made, only a long-term demonstration will establish public confidence and validate the staff assumptions regarding the data, to safely store SNF for an extended period and then safely transport it;
- Develop a communication plan and perform appropriate outreach with affected stakeholders.

3.1. Regulatory reconsideration

The Nuclear Waste Policy Act (the Act) of 1982 directed the Department of Energy to, among other things; work with industry to develop dry cask storage system technologies that could safely store spent fuel. The objective was to establish technologies that the NRC could, by rule, approve for use at nuclear power plants, without, to the maximum extent practicable, the need for additional site –specific reviews. The Act also directed the NRC to develop a streamlined process for licensing dry cask storage systems for use at any nuclear reactor site. The purpose of this directive was to establish acceptable designs that would preclude the need for additional site-specific reviews, because the designs would be safe and acceptable for use at any reactor site that met the constraints of the design.

In 1980, the NRC promulgated requirements in 10 CFR Part 72 governing the issuance of "specific" licenses for independent spent fuel storage installations. In 1986, Surry became the first licensee to receive a specific license to store spent fuel in a dry cask storage system. In response to the Act, the NRC revised the requirements of 10 CFR Part 72 in 1990 to incorporate a "general" license process and an approval process for dry cask storage systems. In April 1993, Palisades became the first utility to use their general license to store spent fuel in a dry cask storage system.

While the regulatory system has served the U.S. well, after nearly two decades of experience and the possibility for the renewed licensing for the foreseeable future, it is appropriate to evaluate the current regulatory process to identify and subsequently implement enhancements. The NRC has a significant challenge to prepare for the evolving national program for SFM and anticipated VLTDS of SNF as the Administration and Congress consider alternatives to the planned repository at Yucca Mt. Partially in response to this challenge, and based on direction from the Commissioners [1] the staff is preparing to identify and recommend potential changes to NRC processes for licensing spent fuel storage facilities and certifying spent fuel storage and transportation systems. The purpose of this review would be to improve the effectiveness and efficiency of our regulatory system in preparation to: 1) support continued power reactor onsite extended storage of spent fuel, 2) facilitate review of expected new away from reactor interim/centralized/regional storage, and 3) streamline the regulatory process, possibly by combining elements of 10 CFR Part 71 and Part 72 to have a more efficient method to regulate the safe and secure storage and transportation of SNF.

The evaluation would consist of:

- Reviewing the current licensing/certification processes, including: 1) regulations, 2) regulatory guidance and standards, and 3) staff operating guidance and procedures;
- Identifying areas where the program can be risk-informed (through expert elicitation and research);
- Identifying areas where the program can be made more efficient and effective, including consideration of how the rulemaking process is used to certify spent fuel storage systems and potential combination of spent fuel storage and transportation requirements;
- Identifying means to make the program more predictable and transparent to applicants and other stakeholders;
- Address new regulatory issues associated with transporting very old fuel — repackaging, design of transfer systems, adequacy of ageing analysis, etc.

The staff will continue to ensure that the NRC spent fuel storage and transportation programs continue to ensure adequate protection of public health and safety and protection of the environment and common defence and security.

3.2. Evaluation of the technical position

In 1997 and 2003, the Electric Power Research Institute (EPRI) evaluated and documented the information needs and the potential sources of the information necessary to provide a technical basis for the safe storage of SNF for 100 years. While adequate, the EPRI documents were limited in their scope and there have since been changes in in cask system and fuel properties. Examples include:

- Only UOX, not MOX, fuel was considered;
- New cladding and fuel compositions and assembly designs are being used;
- Only lower burnup fuel (<45 GWd/MTU) was originally analyzed. The industry is currently burning fuel to 62.5 GWd/MTU and is considering higher burnups;
- Increasing heat loads in dry storage casks systems changes the temperature profile of the cask component;
- Influences of underground and coastal environments;
- Degradation of concrete and many other system components was only briefly discussed;
- Security was not evaluated.

In addition, a number of new concerns have arisen due to: 1) the duration of storage now under consideration, 2) decommissioning of reactors that leave legacy sites that may not have adequate fuel handling facilities for repackaging, and 3) worldwide climate concerns. These issues include but are not limited to:

- Condition of fuel, and basket in a sealed canister;
- Degradation conditions that could require repackaging; what are they and when could they be expected to occur;
- Required long-term monitoring and inspection;
- Ageing management and records retention requirements;
- Influence of very long term storage on transportability;
- Transportation issues caused by lower temperature of fuel;
- Loss of institutional control.

In short, the conclusions of the EPRI evaluations need to be revisited to determine current information needs. This is necessary to determine the appropriate technical research to be conducted and coordinated, so that long-term dry storage of SNF can be effectively and efficiently regulated. The expected outcome of this evaluation would be a prioritized list of information needs and a recommendation of the most effective means, e.g., confirmatory testing, to obtain the information. Our current expert elicitation on the information needs would be replaced with a technically sound evaluation of the situation.

3.3. Research to determine regulatory relevance of technical issues

Until the initial evaluation is complete, it is unknown how many issues will need to be addressed. The starting point is the prioritized list of issues that result from the initial evaluation. To the extent possible research on current issues might be expanded, modelling techniques might be applied, and new cooperative research projects conducted. Until the initial evaluation is completed the extent that additional laboratory research is needed is uncertain and won't be discussed further in this paper.

3.4. Long-term cask demonstration

Examination of low burnup fuel that had been stored for approximately 14 years yielded data that provided the NRC with confidence that low burnup spent nuclear fuel could be safely stored. No comparable data is available for high burnup fuel (HBU) (>45 GWD/MTU) and no demonstration is in progress using high burnup fuel, even though a number of changes in fuel characteristics and potential storage climates, that were previously identified, might raise potential VLTDS regulatory concerns. A long-term cask demonstration program would provide confirmatory data to evaluate and determine if the extrapolations that were made from short-term data remain valid, and would allow any unforeseen aging effects detrimental to the long-term dry cask storage system performance to be identified and appropriately dispositioned in a timely manner.

Even after an alternative to Yucca Mountain is identified, it will take time for DOE to develop and implement the new program approach, thus necessitating the likely need for long-term storage. Monitoring of a variety of aging mechanisms, such as concrete degradation or corrosion when materials are exposed to a coastal environment, will allow NRC to determine what a technically driven long-term aging program should include without placing undue burden on a licensee. Monitoring of the test system might also identify potential issues within the sealed canister that may require actual monitoring in place of analytic resolution.

Four potential preliminary options have been identified to obtain the necessary data:

- A new or modification of international demonstration tests to satisfy US data needs. Currently planned international demonstrations do not meet the US needs in terms of the burnup levels of the fuel, degree of initial characterization, or maximum fuel temperature to be incurred. To our knowledge, the only currently planned international demonstrations are in Japan and Korea;
- Work with a utility to periodically examine already stored spent fuel and internal cask components. A small but significant volume of different types of high burnup SNF is already in storage in a number of different cask configurations. Since it would probably take a minimum of 3-5 years to do the planning and acquisitions to do a new test, examination of fuels and systems already on the storage pad would provide information at an earlier time. Such a test would suffer the same shortfalls as the Idaho test, namely the initial conditions of the fuel and internal components would not be known thus increasing the uncertainty in the final conclusions. In addition, examination of the fuel would require either retuning the cask to the pool for fuel removal, or obtaining an exemption to transport the cask to a facility with a suitable hot cell that has the capability to handle the fuel. In addition, the time-temperature profile of the fuel in currently loaded casks would not be known;
- Initiation of a new independent demonstration test. The number and types of cask systems, types and condition of the fuels used, pre-test fuel characterization, monitoring samples types of monitoring and frequency of monitoring all have the potential to be designated thus setting the demonstration to yield the greatest amount of information. This type of demonstration would require regulatory exemptions, many small volume fuel movements to minimize effects of high temperatures prior to the testing, fuel movement, availability of hot cells, availability of cask systems, willing hosts, and significant funding;
- Monitoring an array of fuel assemblies in a controlled atmosphere in a hot cell while monitoring existing cask system performance by instrumenting and emplacing aging monitoring plans at select utility sites. This option has the potential for reduce costs and fewer logistic problems. Fewer assemblies, transported in small shipments are needed,

and the cask monitoring could take advantage of the time casks have already been on the pad. It does entail though a long term hot cell commitment.

As seen, each of the above options has its own strengths and weaknesses that would have to be evaluated. It is expected that the demonstration program will last until a final disposition option for the fuel is available. There would be periodic monitoring at a frequency and scope to be determined, while the cask is on the storage pad. At reasonable intervals (~15 yrs) the cask might be moved to a hot cell for examination of the internals. The extent of the examination will be determined by the issues that are being monitored.

The results from this demonstration program will provide the NRC with confidence that short-term testing results can be extrapolated to long-term performance by having actual baseline data for one or more particular situations. It will confirm if staff degradation predictions are correct, and identify new phenomena before all storage casks are affected so that appropriate regulatory action can implemented.

4. COOPERATIVE PROGRAMS

EPRI led a meeting with the DOE, NRC, Nuclear Energy Institute (NEI), representatives of the utilities, and cask vendors, to discuss a path forward to obtain the necessary information to be prepared for VLTDS. There was reasonable agreement that the steps outlined above, with the exception of the regulatory reform, were the right path to follow and the parties agreed to share data and insights to leverage activities in this area. A steering committee with a charter and three working groups (one for each task) were formed. International participation would be sought as applicable.

The NRC has an activity underway to evaluate the data needs. That evaluation is expected in 2011. It is the NRC's intent to have the industry, DOE, EPRI etc. conduct as much of this research as possible. NRC would perform appropriate regulatory oversight roles such as evaluating and reviewing pre-test examination plans, and aging management plans, evaluating results, reviewing periodic examination plans, and independently evaluating the performance data obtained. It is not the intention of NRC to operate the test, or do the examinations. Due to the different responsibilities of each participant in the regulatory process, the results would be shared among all participants for their own evaluation of the resultant data.

Established relationships with other foreign regulatory bodies will be expanded to include the topic of VLTDS. One-on-One discussions have been and will continue to be held with representatives of Germany, United Kingdom, and Japan to maintain awareness of their programs, and possibly share technical data or participate in their programs on VLTSD. It is expected that the NRC will continue to provide leadership with the international community and leverage the results of their programs where possible.

5. COMMUNICATION WITH STAKEHOLDERS

Stakeholder involvement is imperative for a number of reasons; 1) openness so external stakeholder are aware of NRC planning activities, 2) solicitation of new ideas, concerns, and approaches, and 3) cooperation in funding, and conducting the program. To date five primary groups of stakeholders have been identified:

- Internal NRC organizations;
- Nuclear Industry (i.e. EPRI/NEI/Cask Vendors/Fuel Vendors/Utilities, National Academy of Science (NAS));

- States/Federally Recognized Tribes/Public;
- Other Governmental Agencies — Department of Energy (DOE), Department of Homeland Security (DHS), NWTRB;
- International counterparts.

NRC staff has already established many international contacts with researchers, government regulatory groups, and foreign utilities. It is expected that these contacts will continue and be used to reinforce the NRC position concerning VLTDS. SFST actively participates in IAEA activities, holding chairs of many committees. The Spent Fuel Performance Analysis (SPARIII) cooperative research program will be used to foster support for required technical studies. Presentations will be made at international forums such as IAEA meetings, Packaging and Transportation of Radioactive Materials (PATRAM), etc. We can learn from them, cooperate with them, and leverage our programmatic results with information exchanges.

6. CONCLUSIONS

With the withdrawal of the Yucca Mountain application, it appears that VLTDS of SNF (including high burnup SNF) will be a necessary part of any future scenario for the safe and secure management of SNF and high level waste in the US. While there is no data to indicate that high burnup SNF can't be stored for long time frames and then transported, the staff currently believes that additional data is necessary to support VLTDS and subsequent transportation without repackaging. NRC has undertaken the task of identifying any informational needs that are required to regulate the VLTDS of high burnup SNF while maintaining the ability to transport it to a final destination in a large cask.

The regulatory process and subsequent guidance to the industry will be evaluated by the NRC based on the results of a program to evaluate the potential data needs, and conduct short term laboratory research to determine if these needs warrant regulatory concern. A long term cask demonstration to both validate the results of the research, determine if new degradation processes are emerging, and provide data for license extension, will be conducted. The experimental programs will be carried out in the framework of a loose consortium of NRC, DOE, utilities, EPRI, and the cask industry, with each participant using the information generated in the program to meet their unique needs. It is the intent to use on-going programs to the greatest extent possible and solicit international participation where feasible.

ACKNOWLEDGEMENTS

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CONSTRUCTION OF FIRST PHASE OF SPENT FUEL REPOSITORY IN FINLAND: LESSONS LEARNED AND SUCCESS FACTORS

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Abstract

The Finnish nuclear legislation defines spent fuel as nuclear waste and requires that it has to be disposed of in the Finnish bedrock. Over 30 years of systematic R&D has been carried out to develop the repository conccept, site selection, technologies, safety assessement and the regulatory approach. Activities are based on the Finnish Government's long term strategies since 1983 and the public acceptance at local, Governmental and Parliament levels, approved and documented in the legal "Decision in Principle" (DiP) in 2000 to locate the repository at Olkiluoto. The DiP provided authorization to construct the first phase of the repository to the depth of the planned disposal. The construction of the 1st phase of the repository started 2004 and has now reached the depth of 407 m. This paper identifies and discusses lessons learned and key success factors of the progress made.

1. THE FINNISH BACK-END OF FUEL CYCLE

As of today, Finland has four power reactors in operation. The Loviisa plant comprises of two 490MWe VVER units, operated by Fortum Power and Heat Oy, and the Olkiluoto plant two 860MWe BWR units, operated by Teollisuuden Voima Oyj. The Loviisa units were connected to the electrical network in 1977 (unit 1) and 1980 (unit 2) and the Olkiluoto units 1 and 2 in 1978 and 1980, respectively. In addition, a new EPR 1600MWe nuclear power plant unit is under construction at the Olkiluoto site.

In April 2010, the Finnish Government approved two of the three applications to construct two more nuclear power plants in Finland. At the time of writing this, the Government's decisions have been submitted to the Parliament for endorsement.

At Olkiluoto and Loviisa sites there are wet-type interim storages for spent fuel as well as final repositories for medium and low level radioactive wastes.

2. CURRENT CONSTRUCTION SITUATION

As of 7.5.2010, the status of the construction of the first phase called "Onkalo" is shown in figure 1. Onkalo will first function as an underground rock characterization falicity to ensure the suitability of the Olkiluoto site for repository purposes and then as an access route to the actual reposity. The construction of Onkalo therefore already means "de facto" construction of the disposal facility because the access tunnel, the shafts and other underground parts will be utilized during disposal operation. However, the construction license application, needed before starting construction of the encapsulation facility and the first disposal tunnels and deposition holes, is expected 2012. The operating licence process is scheduled to take place around 2020.

Onkalo access tunnel excavation has progressed to the length of 4250 m and to the depth of 407 m. Also, two ventilation and one personnel shaft were constructed to the depth of 290 m. Despite complexity of the work and challenges involved, no unexpected delays or problems have been encountered. The construction of the first phase is expected to reach final depth of 420 m during 2010.

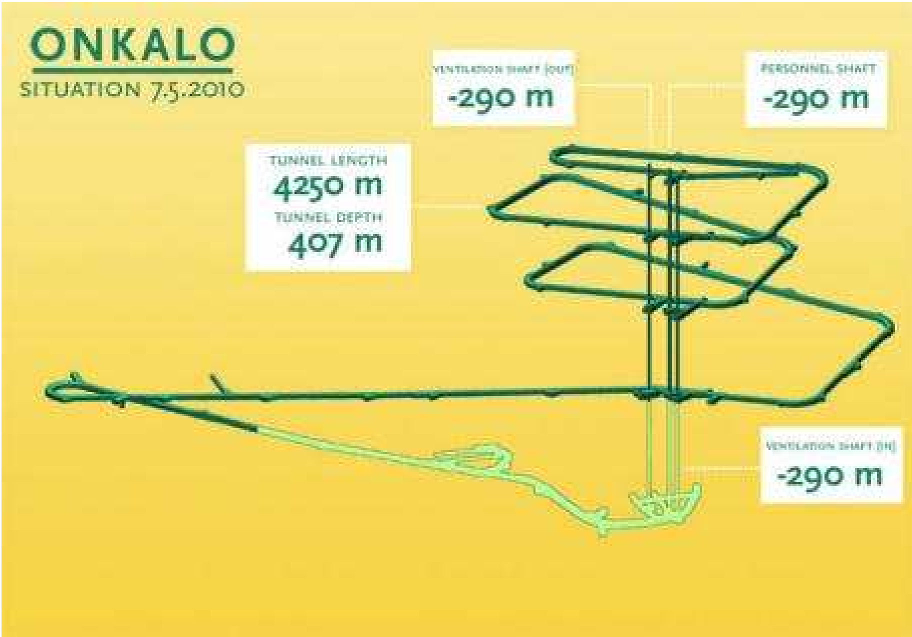

FIG. 1. Construction situation of "Onkalo" (Picture courtesy of Posiva).

3. LESSONS LEARNED AND SUCCESS FACTORS

Finnish experience and lesson learned this far have been translated into success factor, which are discussed in the following. It is emphasized that in the authors' view, while the "Success factor 1" is the most important one, the other success factors 2– 9, are not (necessarily) in the order of importance.

3.1. Success factor 1: Long term political commitment to resolve the nuclear waste issue

The national SFM policy was formulated in the Government's decision in 1983, stating: *In dealing with spent fuel, international central repositories should be made use of where possible because the total amount of spent fuel arising from the operation of domestic nuclear power plants will remain small. The aim continues to be achievement of contractual arrangements through which the reprocessing waste or spent fuel can be transferred and disposed irrecoverably outside the domestic territory. However, in case of spent fuel for which this kind of contractual arrangements are not achieved, the licensees must provide preparedness for carrying out the final disposal in Finland in a safe and environmentally acceptable way.*

The Government Decision also established a schedule for the development of a spent fuel repository, to be followed in case the primary goal could not be met. The disposal site was to be selected by the year 2000, construction of the repository should start around 2010, and disposal should start around 2020.

This policy with the primary and secondary goals remained valid until mid-1990. The licensee of the Loviisa NPP had contractual arrangements for the return of spent fuel and during 1981-1996 about 330 tU of spent fuel was shipped to the Mayak facilities in Russia. The licensee of the Olkiluoto NPP could not find any satisfactory contractual arrangement and started a programme for direct spent fuel disposal in Finland, including site investigations. The interim storage capacity for spent fuel at Olkiluoto was extended by building an on-site wet-type facility.

A new policy was formulated in 1994 by the amendment of the Nuclear Energy Act, stating: *Nuclear waste generated in connection with or as a result of the use of nuclear energy in Finland shall be handled, stored and permanently disposed of in Finland. Nuclear waste generated in connection with or as a result of the use of nuclear energy elsewhere than in Finland, shall not be handled, stored or permanently disposed of in Finland.*

One reason for the policy change was that Finland joined the European Union in 1995 and there were public and political concerns that Finland, having advanced nuclear waste disposal programs, might be compelled to accept nuclear waste from other EU countries.

3.2. Success factor 2: National strategy and discipline

The Government's decisions discussed above, included major milestones and timeline for the waste holders and STUK. Plans and results have been regularly reviewed by STUK and accepted on Ministry level to ensure that the waste holders are carrying out, and committing appropriate resource for, the needed activities.

3.3. Success factor 3: Well defined liabilities and roles

Per legislation, a licensee, whose operation generate nuclear waste, is responsible for all nuclear waste management measures and their appropriate preparation, and is responsible for the arising expenses. The NPP utilities FPH and TVO themselves take care of interim storage of spent fuel, of management of LILW including disposal, and of planning for the decommissioning of the NPPs. Their jointly owned company, Posiva, is taking care of the preparations for and later implementation of spent fuel encapsulation and disposal.

Licensing of nuclear facilities in Finland has three separate steps. The first one is a political decision by Government, called Decision in Principle (DiP). The content of the decision is simply that "*the new nuclear facility is in line with the overall good of the society*", and it has to be endorsed by the Parliament before it enters in force. Other two steps are Construction License and Operating License, both of them issued by the Government. These two steps have been more or less technical decisions. In all steps, Ministry of Employment and the Economy provides administrative support to the Government by processing license applications.

STUK is the independent regulatory authority responsible for oversight of nuclear and radiation safety. It drafts all mandatory nuclear safety regulations that are then issued as Government Decrees, and more detailed guidance for applying the regulations are given in regulatory guides (called "YVL guides") issued by STUK. In each license process, a favouring safety appraisal by STUK is a necessary condition for issuing the license. After a license has been issued, it is the task of STUK to verify through inspections that the required safety arrangements are made and the facility remains safe and in compliance with license conditions over the plant lifetime. STUK also conducts all required inspections on nuclear waste management and nuclear material safeguards.

3.4. Success factor 4: Early on established funding system

The "polluter pays" principal, which included all costs (also R&D and regulatory costs) is followed. The Nuclear Energy Act provides detailed regulations for the financial arrangements for nuclear waste management and the Decree on the State Nuclear Waste Management Fund further specifies the financing system. Generators of nuclear waste are annually obliged to present justified estimates of the future cost of managing their existing waste, including spent fuel disposal and decommissioning of NPPs. The Ministry of Employment and the Economy confirms the assessed liability and the proportion of liability to be paid into the Nuclear Waste Management Fund (fund target). The waste generators pay annually the difference of fund target and the amount already existing in the Fund. The waste generators shall provide securities to the Ministry for the portion of financial liability that is not yet covered by the Fund.

The current estimates arise to about 1900 million Euros with no discounting.

3.5. Success factor 5: Veto-right for the local community regarding hosting the repository in a stepwise licensing process

The Nuclear Energy Law clearly states that "*Before making the decision-in-principle, the Government shall ascertain that the municipality where the nuclear facility is planned to be located in its statement is in favour of the facility*". This has implied, among other things, that the local municipality has been able to study and review all aspects (financial, socio-political, technological, safety etc.) it has felt appropriate without risk that Government, or even Parliament, is able to force the municipality to host the repository against their will.

3.6. Success factor 6: Regulator's strategic planning to allow development of regulatory approach parallel with R&D and in analogy with nuclear plant safety regulations

Developing regulatory approach has been challenging, mainly because there is no earlier experience of this kind to learn from.

The main principles for development of the regulatory approach for nuclear waste management in Finland are following:

- We must not leave nuclear waste as a burden to future generations;
- We must take care of safe disposal of nuclear waste and spent fuel by using today's proven technology;
- We must be able to manage our nuclear waste without a need to rely on foreign support;
- High level protection of workers, the public and the environment;
- No future detriments exceeding currently acceptable levels;
- No reliance on long-term surveillance;
- Implementation of disposal with due regard to safety and with appropriate timing of the various steps of the disposal process;
- Ensuring the operational and long-term safety;
- Continuous safety improvement;
- Making use Joint Convention and IAEA's safety standards.

Over the years the Finnish nuclear legislation, regulations issued by the Government and binding regulatory guides (YVL-Guides) issued by STUK, have been developed and modernized parallel with the progress and findings of R&D. The latest Government Decree dealing with spent fuel disposal safety was issued 2008 and the renewal of the corresponding regulatory Guide YVL D5 has also been updated and is in the process of publishing.

STUK has re-organized and expanded its staff and operations in response to the progress of the disposal project and expanding operations of Posiva. In particular, STUK developed and started implementing a new regulatory approach for inspection and review of ONKALO and Posiva's activities. STUK's inspection program utilizes a graded approach based on safety importance of the repository's structures, systems and components. Domestic technical support organization (State Research Center, VTT) and four international standing advisory groups support STUK in regulatory review of the repository issues.

The current YVL Guide D5 sets requirements and obligations to radiation protection (for operation of the disposal facility and for long term safety), planning of the disposal method (stepwise implementation, barriers and safety functions, disposal site and facility), design of the disposal facility and practices (radiation protection design, design of structures, systems and practices, prevention of incidents and accidents), operation of the disposal facility, demonstration of compliance with safety requirements (principles of safety demonstration, safety analysis report and attached documents, safety case, periodic safety reviews) and regulatory control.

Table 1 illustrates the overall stepwise development process.

TABLE 1. STEPWISE PROGRESS OF THE REPOSITORY PROGRAM

Period	Implementation	Regulatory oversight
1983-1999	-Conceptual design, research and development -Site selection process: 100 > 5 > 3 -Detailed site investigations	-Government's policy of 1983 -STUK's safety reviews of 1987, 1994 and 1997
1997-2001	-EIA program and report -DiP application for a disposal facility at Olkiluoto	-Safety regulations 1997 -EIA hearings and judgement -STUK's preliminary safety appraisal as part of DiP process
2000-2012	-Confirming site investigations, including underground rock characterization facility ("Onkalo") -Research and technical development, start detailed design	-Updated safety regulations 2008 -Oversight of site investigations and construction of "Onkalo" -Review of the state and plans of research and technical development, in three year periods
2012-2020	-Construction licence application -Construction of the facilities	-Review of licence application -Oversight of construction
2019-	-Operating licence application -Operation of the facilities	-Review of licence application -Oversight of operation

In the following, developments of selected elements of the regulations are discussed:

The radiation protection criteria: Radiation protection criteria have been developed over the years and resulted in specifying separately criteria for different time periods, which are (1) Operational period (about 150 years), (2) reasonably predictable future (several thousands of years), era of extreme climate changes (hundreds of thousands of years) and (4) farthest future (million years and beyond).

3.6.1. Operational period (about 150 years)

For the operational period, dose-based radiation protection criteria are used as follows:

— Practically no releases from normal operation;
— 0.1 mSv/a for anticipated transients;
— 1 mSv/a for postulated accidents with probability > 10–3/a;
— 5 mSv/a for postulated accidents with probability < 10–3/a.

3.6.2. Reasonably predictable future (several thousands of years)

Reasonably predictable future starts from closure of the repository and lasts for several thousands of years. It is expected that during that time boreal or temperate climate will prevail. However, considerable environmental changes will occur due to e.g. land uplift. Geological conditions are stable or change predictably (e.g. groundwater chemistry). Radiation protection criteria are based on doses (or dose expectancies) to members of hypothetical critical groups due to early failure scenarios. These are following:

- Highest individual doses from expected evolution scenarios < 0,1 mSv/a;
- Insignificant average doses to larger population groups.

Whenever practicable, the consequences and expectancies of radiation impacts from unlikely disruptive events shall be assessed in relation to the constraints. Critical group is a self-sustaining community in the environs of the disposal site. Potential impacts on species of fauna and flora are also examined.

3.6.3. Era of extreme climate changes (hundreds of thousands of years)

The era of extreme climate changes starts after several thousands of years and continues for about 200000 years. Glacial or permafrost climate type takes place at 10000 - 60000 years from now. The range of potential environmental conditions will be very wide and dose assessments would be meaningless. Major geological changes (groundwater flow and chemistry, rock movements) will occur, but their ranges can be estimated. Radiation protection criteria are based on release rates of radionuclides from the geosphere (geo-bio flux constraints). Maximum impacts must be comparable to those arising from natural radionuclides, and large-scale impacts must be insignificant. Nuclide specific release rate constraints are given by STUK.

A useful way to put the time scale in perspective is to compare the radioactivity of the spent fuel with the radioactivity of the uranium that was needed for manufacturing of the respective fuel. The time to reach one-to-one ratio is about 200000 years. At defueling the spent fuel radioactivity in this scale is 4 million, after 40 years (start of disposal) 7000, after 500 years 100, and after 10000 years 15.

3.6.4. Farthest future (million years and beyond)

Beyond about 200000 years the potential radio toxicity of spent fuel becomes to the level of that in the natural uranium, from which the fuel was fabricated. The hazard posed by the repository is therefore comparable to that from a uranium ore deposit. No rigorous quantitative safety assessments are required but demonstration of safety can be based on simplified bounding analyses, comparisons with natural analogues, and observations of the geological history of the site.

Safety analysis reports and safety case: In the construction license phase, safety analysis is preliminary (PSAR) and based on site and repository system's design. In Operating license phase safety analysis is final (FSAR) and based on site and actual, constructed systems, components and structures and using the actual conditions and parameters.

Compliance with the requirements concerning long-term radiation safety, and the suitability of the disposal method and disposal site, is proven through a safety case that analyzes both expected evolution scenarios and unlikely events impairing long-term safety. The safety case comprises a numerical analysis based on experimental studies and complementary considerations insofar as quantitative analyses are not feasible or involve considerable uncertainties. The scenarios shall be systematically constructed from features, events and processes which may be of importance to long-term safety and which may arise from:

- Interactions within the disposal system, caused by radiological, mechanical, thermal, hydrological, chemical biological or radiation induced phenomena;
- External factors, such as climate changes, geological processes or human actions.

In the Finnish licensing system, taking analogical approach of PSAR and FSAR, the approach of "preliminary safety case (PSC)" and "final safety case (FSC)" is used. In the construction license phase, PSC is based on site and design and the results are documented in the Preliminary Safety Case. In Operating license phase, FSC is based on site and actual systems, components and structures (incl. bedrock conditions) using the conditions, parameters etc as found in constructed environment.

3.7. Success factor 7: Well structured, stepwise, open and defendable implementation program using graded approach and "rolling documents" strategy

The Finnish spent fuel disposal program has been implemented in accordance with the target schedule established in the Government's policy decision of 1983. Site selection, engineered barrier and safety analytics have been developed parallel and in connection with each other.

The waste management company Posiva responsible for the repository project has continued to expand and strengthen its activities and resources. Substantial progress has been achieved in the areas of site characterization (geology, rock mechanics, hydrogeology, hydrochemistry, prediction of properties and impact of construction, consistency and confidence assessment and integrated site description); features, events, processes (FEPs); evolution studies (climate, site, and repository); scenarios; engineered barrier system (copper canister, bentonite buffer, backfill); radionuclide transport; biosphere; safety assessment and the safety case. Posiva has continuously submitted large number of documents to STUK for regulatory review.

As an practical example of the structured and stepwise approach is the site screening. The site screening results were published in 1985 and the site investigations started a couple of years later. Six sites were subject to deep drillings and other surface based investigations, two of them being the NPP sites Olkiluoto and Loviisa. The final choice, involving e.g. environmental impact assessment (EIA) processes, was done between four sites. Of them, Posiva Oy picked in 1999 the Olkiluoto site as the preferred disposal site. The process is illustrated in fig. 2.

Another important element of the stepwise approach has been reporting and submitting safety technical plans, work and results to regulatory review in a stepwise manner. This so called "rolling document" approach has had considerable benefits, such as providing early feedback on open and closed safety issues, improving regulator-implementer dialogue, increasing better understanding and use of different professional views, improving transparency and openness, improving traceability of results and conclusions important to safety, supporting development of safety culture etc.

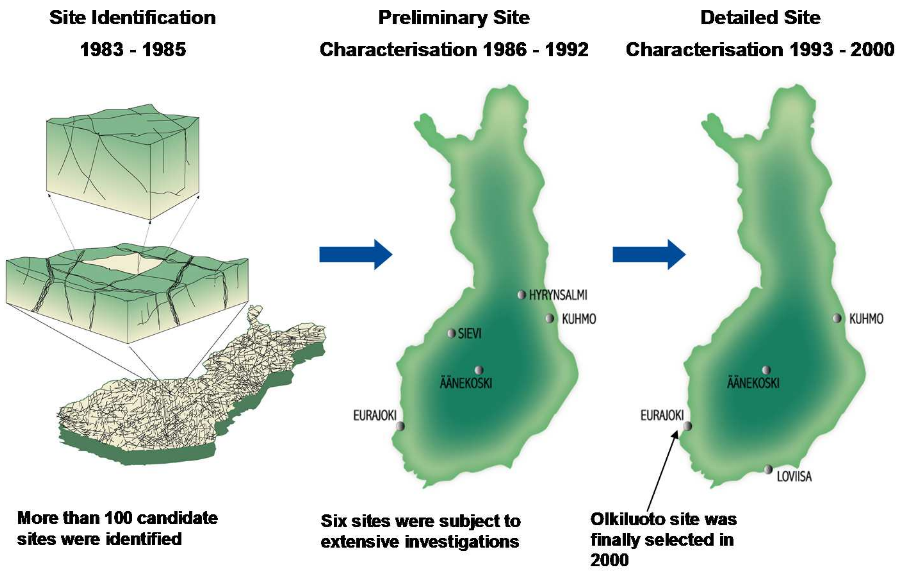

FIG. 2. Stewise process in site selection (Picture courtesy of Posiva).

3.8. Success factor 8: Good safety culture and importance of dialogue between the regulator and the implementer based on comparable levels of technical competence

Safety is made in every working level by every individual. Therefore safety is influenced by how any organization is managed, what kind of atmosphere and culture there is and what kind of attitudes the management has and reflects to the staff, both verbally and non-verbally.

In regulating the disposal program, STUK has also covered Posiva's safety culture issues. Some examples are given below.

3.8.1. Visible commitment of the management

Asking examples of decisions where safety comes before finances and schedule; resource allocation to safety issues; active participation in dealing with safety issues and acquiring needed competence; safety positive attitude with stakeholders (own organization, public, media, authorities, regulators); rewarding based on safety initiatives.

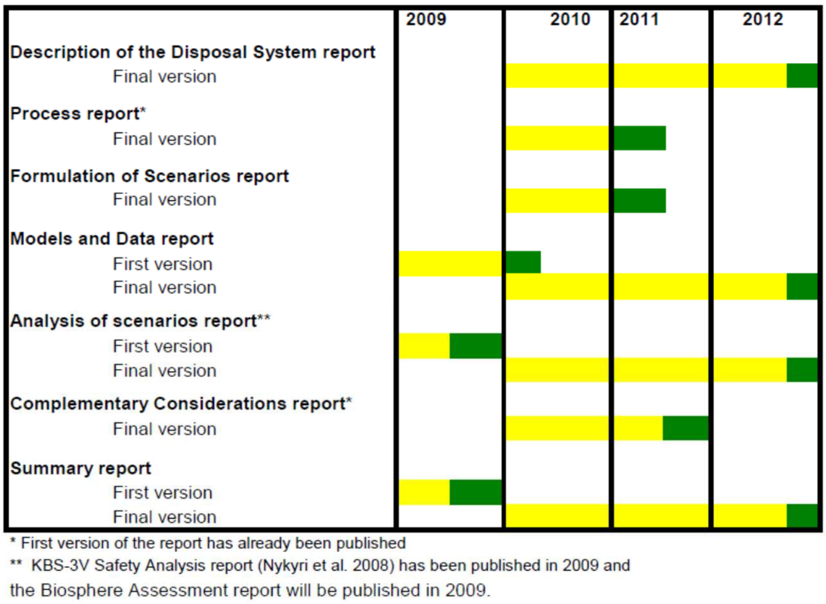

FIG. 3. Example of the "rolling documents" approach (Picture courtesy of Posiva).

3.8.2. Conservative decision making

Selecting the safer option in an uncertain situation; when facing unexpected problem, halting work and consulting superiors; superiors' positive and supportive attitude towards halting the work, if there emerges doubt about the correctness or safety of a situation; support staff to seek for expert advice and additional information, avoiding all kinds of inspirational actions.

3.8.3. Reporting on deviation and anomalies

*T*he sincere attitude of the whole organization to report deviations, mistakes made, and observations experienced; blame free culture; positive attitude toward self-reported mistakes; reacting to deviation and anomalies, and finding courses promptly.

3.8.4. Reacting to factors weakening or jeopardizing safety

"To tolerate is to validate"; do others tolerate poor safety performance of others; is untidiness and disorganized tolerated ?

3.8.5. Intention and ambition to learn from experience

Does the organization have a published policy of continuous improvement, to do things better than before; is staff engaged to suggest initiatives for improvements in particular in their own area of responsibilities; are there established and clear channels for staff to make such suggestions; are such suggestions appreciated and taken seriously also in practise; is the staff offered opportunities to make comparisons with other respective organizations; is organizations effectiveness, structures and processes, resources and finances, renewal and ability to function and work regularly assessed by internal (such as self-assessment) and external efforts.

3.8.6. Prioritization

*S*election of safety improvements based on priorities, and clear justification of priorities as well as selections made; avoiding non-specific "wish-lists"; setting realistic goals and time schedules to the prioritized initiatives and projects, sufficient resource allocation, determined and focused implementation and completion of the prioritized initiatives and projects.

3.8.7. Ability to produce required quality

Ensure that contractual arrangements with supply chain organizations include all relevant safety and quality requirements; before selecting a contractor, ensure that it has demonstrated ability to produce the required quality products.

3.8.8. Safety and quality at the Onkalo construction site

Creating the technical and organizational precondition to the safety, is it understood that safety culture is important during construction, because poorly constructed seldom can operate safely and reliably; carefulness and systematic arrangements for the whole construction site, professionalism of all workers?

In addition, STUK has followed practical guidance affecting safety culture as

- No need to intervene, when corrective actions are already taking place;
- Find professional and value adding balance: too eager interference will have counterproductive results with respect to informing regulator about deviations and problems;
- Equal level of competence, in case of different professional opinions; regulator must be able to strong justification;
- Aim at open and fair communication with the licensee and contractors;
- Regulator should act consistently and in a predictable manner:
  - Every actor in the supply chain must be informed about the safety requirements and acceptance criteria, which are relevant to that actor, before the design stage;
  - Coherent, not person dependent means and ways of communication;
  - One issue - one approach - one "regulator";
  - All formal decisions must be processed, documented and filed in accordance with quality system.

3.9. Success factor 9: Transparency and engagement of public and domestic and international scientific and technical communities

After early ad hoc events, public consultation processes both by STUK and Posiva were systematized based on several studies and surveys made on the need of the public in order to facilitate and inspire their participation. In particular, this was important on local level, because the legislation gives the host community a veto right, which can't be over-ruled by the Government or the Parliament, on repository hopsting issue.

Both Posiva and STUK are, on continuous basis, engaging national and international experts in the repository project. In particular, Posiva has a major co-operation program with the Swedish SKB and many other joint projects with EU and other partners.

STUK and Posiva consider this kind of international involvement, which is deeper than normal bi- and multilateral (IAEA, OECD/NEA) co-operation, vital from professional research, development and sparring viewpoints and equally important from the viewpoint of openness to the national and international scientific and technical communities.

As practical examples, STUK has the following standing international expert and advisory groups (members from France, Germany, Sweden, Switzerland, UK, USA and few from Finland):

- SONEX, dealing with Olkiluoto site characterization issues;
- AEGIS, dealing with engineered barried issues;
- SAFARI, dealing with safety analysis and safety case issues;
- NWSG, waste safety advisory committee, which is dealing with strategy level waste safety, issued advising the STUK Director General.

In addition, over the years there have been several peer reviews on the disposal project. The latest one, EU-27 peer review, took place November 2009 and was targeted on STUK's activities. The program, peer review report and STUK's action plan can be found from www.stuk.fi

4. CONCLUSIONS

The 1st phase of the spent fuel repository in Olkiluoto, Finland has currently reached the depth of 405m. Over 30 years of systematic R&D has been carried out to develop the repository concept, site selection, technologies, safety assessment and the regulatory approach. Lessons learned have been translated into nine success factors, the most important of which is the "long term political commitment to resolve the nuclear waste issue" in Finland.

As of today, there are no indication that would suggest that the repository can't be built to comply with safety, security and safeguards regulations set by the Finnish Government and STUK.

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MULTINATIONAL INITIATIVES FOR LONG-TERM SPENT FUEL MANAGEMENT
AN UPDATE ON CURRENT INTERNATIONAL PROJECTS

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Abstract

Discussions continue about the safety and security of both current and future facilities for storing and eventually recycling or disposing of spent power reactor fuel. Whilst current storage provisions appear to cause little security concerns today, the expansion of nuclear power will mean that more and more storage locations appear around the world. There are still no geological repositories for spent fuel anywhere, after more than 50 years of nuclear power. As it is inconceivable that there will be dozens of such repositories worldwide, there is growing emphasis on how to implement shared solutions. This paper looks at three aspects of current activities in this area: a proposed approach to how shared multinational repositories might be sited – possibly the most contentious point raised by sceptics of shared solutions; the practical example of the European Repository Development Organization working group (ERDO-WG) and the components of the model organizational plan and constitution to be put before potential ERDO member country governments within the next couple of years; finally, plans for how the ERDO-WG model might be applied in other regions of the world where shared disposal solutions might be coming of interest. The critical role of the IAEA in pushing these initiatives forward is emphasised.

1. INTRODUCTION

Highly radioactive spent fuel containing fissile plutonium should not end up in numerous locations scattered around the globe as more and more nations, both large and small, expand or introduce nuclear power. A small number of safely constructed and well-secured storage and disposal facilities must be the goal. Storage facilities are already beginning to overflow in some countries using nuclear power. The repositories expected to be in operation by today have not been implemented, either because there has been societal opposition to siting or because they are too costly. Implementing new national wet or dry stores has also proved problematic in some cases. There have been proposals for multinational stores, but importing foreign spent fuel for storage alone is a sensitive political and public issue, if this is proposed without a final disposal solution being agreed. In addition, one of the findings of the first stage of the EC project on shared storage and disposal (SAPIERR I, see below) was that there is little planning, operational or economic advantage to be had in sharing storage facilities on a multinational basis so there are few positive practical drivers to counterbalance the largely negative political reactions.

One option would be for nuclear-fuel suppliers to take back the spent fuel under a fuel 'leasing' arrangement, in which they would provide fresh fuel and take it back after irradiation. They would then add this leased spent fuel to their own larger stocks to be stored for later disposal, or for reprocessing and recycling into new fuel. The concept was included in the Global Nuclear Energy Partnership (GNEP) programme launched in 2006 by the USA, with the goal of restricting sensitive nuclear technologies to a limited number of supplier states. However, the United States has never made a serious offer to take back spent power reactor fuel itself, US funding for GNEP has been discontinued and the whole issue of future management of its own, considerable domestic spent fuel stocks is back under debate and clouded with uncertainty. Of all the nuclear suppliers, Russia has expressed the most support for fuel leasing and take-back and has, for example, agreed to do this for Iran. Russia has not yet offered such services widely, however, and with the current under-developed status of domestic waste disposal projects in Russia itself, some countries (and also the European Commission) would have reservations about such a solution. Consequently, whilst conceptually attractive, leasing and take-back seems to remain as far out of reach of both the emerging and up scaling nuclear power nation potential users and the possible supplier nations as it has been for the last thirty years. In addition, depending on how they were to be set up contractually, leasing arrangements might only solve part of the problem of SFM, as long-lived wastes from recycling might be returned to the user countries for disposal. Whilst global security may have been enhanced, the global problems of the nuclear industry in showing that it can properly manage all of the wastes from the nuclear fuel cycle would not be satisfied.

The most promising option for small and new nuclear power programmes thus continues to be to collaborate with similarly positioned countries in an effort to implement shared, multinational repositories for spent fuel and their other long-lived radioactive wastes, thereby giving themselves a total solution that a) does not depend on services being offered by major providers and b) provides then with an alternative, should such providers offer disposal services only at unacceptably high prices. Accordingly, a key question, in particular for small and new nuclear programmes, is whether it is feasible to establish credible initiatives for multinational deep geological repositories for spent fuel and long-lived radioactive wastes. The answer to this question depends on the crucial issue of identifying technically and societally acceptable host regions for siting multinational repositories.

2. SHARED SPENT FUEL DISPOSAL — THE SITING PROBLEM

The national advantages in sharing disposal technology and in benefiting financially due to the economies of scale in implementing repositories are obvious and have been well explored **Error! Reference source not found.**. The global safety, security, and non-proliferation benefits of helping all nations to have earlier access to state-of-the-art repositories are also clear and have been widely discussed **Error! Reference source not found.**. The big challenge, of course, is in achieving public and political acceptance in the countries where such repositories would be hosted. Many commentators looking at multinational disposal concepts pick on this multinational NIMBY issue immediately as being an insurmountable problem, but it is no different in principle to the national NIMBY problems faced internally within any country that wishes to identify a region and then a site for a national repository — and it can be addressed in exactly the same way as it has been in successful national programmes. In fact, one of the significant advances of the last couple of years has been the development of a possible approach to siting a shared, regional multinational repository that is based upon the bottom-up, volunteer siting methodology that has worked in two or three countries already and that is the cornerstone of the current Japanese and UK siting strategies for their national geological repositories. The approach advocated [6] is a volunteer model incorporating stakeholder involvement at all stages. It is technically guided at the outset only insofar that clearly unsuitable regions are excluded at the start. Consequently, it incorporates the flexibility to evaluate objectively any proposals that might emerge from volunteer communities or regions or countries, from the start of the programme.

An important underpinning aspect of this approach is the initial assumption that any location that is not obviously *unsuitable* on the basis of existing knowledge is worth considering on its merits as a possible repository site. This is the approach currently being taken in the United Kingdom and Japan. It is based on the knowledge that many different geological environments can provide acceptable isolation and containment conditions and that many different repository concepts have been designed to take advantage of this range of conditions. An obvious rider is that a volunteer location (in a non-excluded area) might well be rejected after only limited investigations, if these indicate that it would be too difficult to make a reliable safety case or too costly to adapt designs to site conditions. The essential element, however, is to maintain flexibility and not to exclude interested communities if there is a realistic likelihood that they could prove suitable.

A central matter for discussion with partner countries is how to solicit volunteers: the geographical levels at which volunteers are sought (community, county/district, region, country) and the roles and responsibilities of the actors involved at each level. Several sensitive questions are raised, including:

- Must volunteering countries already have identified potential host communities?
- Does the government of a country have to volunteer actively or, more passively, simply agree not to block any local volunteers?
- Can local communities volunteer before national agreements are reached?
- At which of the above levels is consent to volunteer required?
- How does one define sufficient acceptance at each of the levels?
- Who has veto or withdrawal rights and at which project stages can these be exercised?
- Who negotiates the levels and the distribution of benefits for volunteers?

The answers to these questions are likely to differ across partner countries, but a model has been developed for how the process might be structured, with the approach favoured being to place the initiative firmly in the hands of local communities, once certain boundary conditions have been established. The sequence proposed in the model is:

(1) A group of countries comes together to explore the possibility of sharing a geological repository (as in the ERDO, described in Section 3). Having established the way in which they will work together, they give wide publicity to the project, explaining all aspects including initial aims with respect to national and community benefits, and they announce that a volunteer process will be launched in the near future;

(2) With the involvement of a wide range of national and international stakeholders, they establish a common set of technically based exclusion criteria to remove from consideration clearly unsuitable land areas within all their countries. National databases would play a central role in establishing which areas are affected by the exclusion factors and national agencies (e.g. geological surveys) would likely be pivotal in applying the factors;

(3) Communities in non-excluded areas in all the countries are invited to express interest (on a non-committing basis) in the possibility of being a host for the repository, thus starting the siting process described later in this document. National governments would agree not to stand in the way of this process — indeed, some may actively encourage it;

(4) Participating national governments would be free to solicit specific volunteer communities that they considered might have a particular interest in the project or have particularly favourable characteristics for hosting a repository;

(5) Up to a pre-defined 'point of commitment' (probably after several years of site investigations), both interested communities and national governments would be free to withdraw from the process.

Some additional factors need to be considered in this simple model. For example, partner countries might enter the project at different stages. Only when the largest programmes likely to be in the eventual project are known with more confidence can a realistic estimate be made of the costs of repository implementation and of the scale of benefits and impacts to the host country and community. The size of these will be key factors for any community or country making a decision on whether to move to the next stage of siting inappropriate.

A further question concerns how existing national siting programmes can be incorporated into this model. Partner countries that already have developed national siting programmes will be able readily to pool their knowledge, but they will also have to decide how to deal with sites and communities that are already being considered as possible national repository locations — will these sites be in the 'pool' of potentially interested communities, not in the pool, in the pool at the start or only in the pool later? For some countries this will be an especially sensitive issue to resolve and would clearly need consultation with potential host communities already identified.

The essence of this model is that it takes some of the burden of leadership of a very sensitive project off those national governments, who may be reluctant to be in the vanguard of such a programme. For any national government it requires only that it acknowledges and supports the democratic decision powers of local communities. In fact, it would require local communities to act in an international arena — to consider themselves as potential contributors, not just to meeting a national challenge, but to solving a regional or multinational problem. This is perhaps something relatively new in planning and decision-making, although elements of such a process are already visible in the EU. We believe that such community farsightedness, along with appreciation of the potential economic and societal benefits that would accrue to a host community, may make siting a shared repository considerably less difficult than critics of multinational solutions assert.

3. ERDO: PRACTICAL STEPS FORWARD IN THE EUROPEAN UNION

Over the past few years, significant progress towards shared geological disposal facilities for spent fuel and other long-lived wastes has been made in the European Commission SAPIERR I and SAPIERR II projects, which examined the technical, economic, legal and societal feasibility of shared storage and disposal solutions for some countries in the European Union. The SAPIERR II project, which was completed in 2008, concluded by making proposals for a staged and adaptive implementation strategy for a European Repository Development Organization (ERDO) **Error! Reference source not found.**. The first step in the strategy was to establish a working group (ERDO-WG) of initially interested countries to carry out preliminary work to enable a consensus model for such an organization to be built. Since its establishment in January 2009, the ERDO-WG has met three times and now has the outline of such a model in place. The intention is to refine the model so that it can be presented to potentially interested governments at some point in the next year or two.

The mission statement agreed for the ERDO-WG at its first meeting is:

"Our aim is to work together to address the common challenges of safely managing the long-lived radioactive wastes in our countries. Specifically, we will investigate the feasibility of establishing a formal, joint European waste management organization. The Working Group will carry out all the necessary groundwork to enable the establishment of a European Repository Development Organization (ERDO) as a working entity and present a consensus proposal to our governments. Providing that a sufficiently broad consensus is achieved by our governments or their representatives, the ERDO will be established at the end of this process".

A key aspect of the ERDO-WG has been to ensure that its members represent the governments of the countries concerned and can take back issues arising at meetings for discussion with national decision-makers. To date, ten European countries have participated at some level in the ERDO-WG: Austria, Bulgaria, Ireland, Italy, Netherlands, Lithuania, Poland, Romania, Slovakia and Slovenia. If a sufficient number of partner nations agrees to the final proposals, the ERDO will be established and will eventually operate as a sister organization to waste agencies from European countries that have opted for a purely national repository programme, such as France, Sweden, Finland, and Germany. Consequently, it has been important for ERDO-WG to begin to develop working relationships with these (and other, non-EU programmes) via discussions with the EDRAM group. These have led to the development of a joint position paper on multinational repositories, intended for publication later this year.

Although still in the early stages of development, the organizational model for the ERDO is addressing all the major points that will need to be resolved before a credible body could receive the support of governments. In the following paragraphs, we identify some aspects of the model that are currently being considered.

The ERDO is conceived as a not-for-profit development organization. It will not own or operate any waste management facilities. The objective of the ERDO is to carry out the necessary work to address the common challenges of safely disposing of the long-lived radioactive wastes in its Member Countries by the sharing of knowledge, technologies and facilities. It will carry out all the work necessary to allow construction of one or more geological repositories, including the siting, design, site characterisation, safety and environmental assessment, and strategic and economic planning for the facility or facilities. Before submission of any license applications, the ERDO is likely to make a transition to the most appropriate and mutually agreed form of organization to operate the repository and any other facilities; this organization is nominally being referred to as the European Repository Organization (ERO). The form of the ERO will depend upon the national legislation of the host country, since this will be its domicile.

At present, the ERDO model has been developed to the stage of draft Operating Guidelines and a draft Constitution, which also propose how the organization would be funded. The eventual guidelines are likely to state, among other things, that all member countries must have a national strategic plan for radioactive waste management that meet their obligations with respect to the IAEA Joint Convention and any relevant Directives of the European Commission on radioactive waste management. Member countries with active or past nuclear power programmes would be expected to have an active parallel national programme for R&D, including siting studies, for a geological repository on their own territory in order to fulfil their international obligations (Model A in Figure 1). They would be expected to operate this programme in an interactive and complementary manner to the ERDO programme. In doing so, member countries will receive the benefit of shared R&D and technology development for all aspects of their national radioactive waste management programmes, as well as contributing to shared knowledge. Different rules are expected to apply to member countries with no active or past nuclear power programme. For example, they are expected to be able to choose to opt in or out of the ERDO siting programme for the repository.

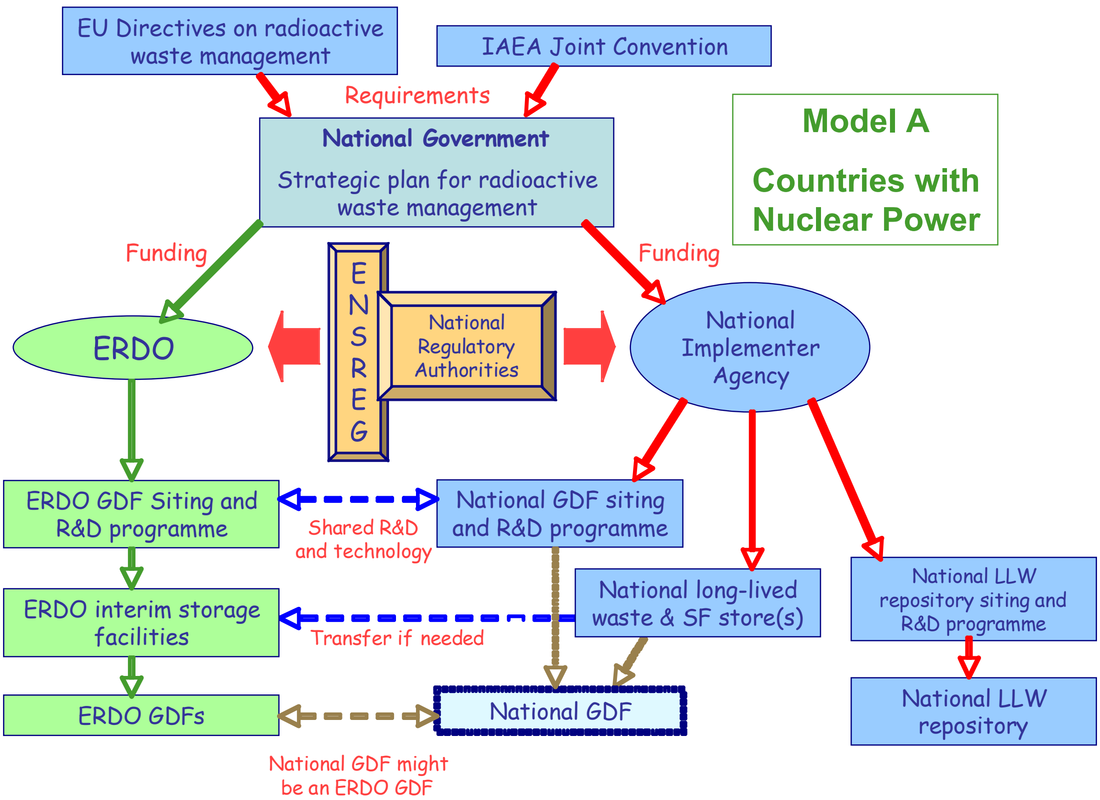

FIG. 1. A model for how the national programme of a country with nuclear power might interact with the ERDO and some other international groups.

All member countries would agree to fund an agreed programme of work of the ERDO, proportionately to an estimate of their inventory of wastes for geological disposal, as cash or in-kind contributions of staff resources and facilities, and the ERDO will operate solely for the benefit of its member countries on a not-for-profit, shared risk basis. If a successor ERO is established, this may decide to offer services to further users on a commercial basis.

It will be important for the ERDO to carry out its work so that it does not interfere with or adversely affect national waste management plans in any of its member countries, including any parallel, national repository development programmes — it is expected that the ERDO will work symbiotically with national programmes. By working closely with national programmes it will share R&D and technologies and produce cost-benefits for all parties during the development stages leading to a disposal facility. Similarly, the ERDO will not operate in such a way as to adversely affect non-ERDO national waste management programmes in Europe. Indeed, as noted above, the ERDO expects to be able to work closely with these organizations too, to the mutual benefit of all parties.

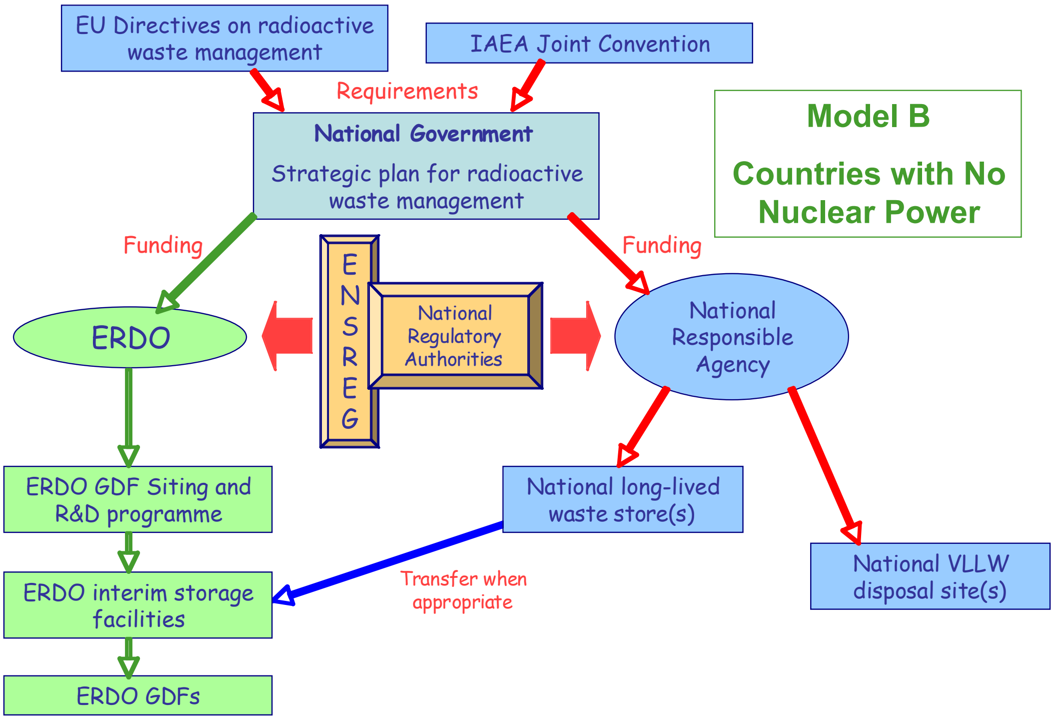

FIG. 2. A model for how the national programme of a country without a nuclear power programme (but with long-lived wastes for disposal) might interact with the ERDO and some other international groups.

The overall objective of the ERDO will be to develop a repository operational plan (including any associated storage and other facilities identified as necessary) that makes safe and secure waste disposal facilities available at the minimum cost to member countries, taking account of all actual development, operational and closure costs, including benefits to the host community, region and country.

In order to provide transparent oversight and ensure the use of the most appropriate technologies and internationally recognised safety standards, the ERDO may decide to submit its work to technical audit by the IAEA and to regulatory overview by the European Nuclear safety Regulator Group (ENSREG), or their agreed representatives, and the regulatory authorities of the repository host country. In any case, the ERDO will maintain close links with the IAEA, the European Commission and other national and international organizations.

At an agreed time, the ERDO will make a transition to a European Repository Organization (ERO). This is expected to take place before the repository enters the licensing process, so that the license applicant will be the eventual operator of the facility. ERDO member countries will be guaranteed access to ERO facilities at charges that will be agreed before this transition takes place.

The ERDO-WG will generate over the next 1-2 years the decision input needed for Governments to decide whether to proceed with the formal establishment of an ERDO. If there is sufficient agreement to do so, a domicile, staffing structure and initial programme will be agreed as a basis for the work of the ERDO over the next 10 or more years.

4. EXTENDING THE ERDO CONCEPT WORLDWIDE

The long-term objective of the Arius Association is to improve global nuclear security by promoting timely provision of safe and secure, shared solutions for reactor fuel disposition at a time when we expect considerable global expansion of nuclear power. The process and concepts described above, in Section 3, could demonstrate to other regions of the world the feasibility of enhancing safety and security while increasing the economic attractiveness of nuclear power, even for small countries. ERDO could act as a role model for regional groupings elsewhere.

In collaboration with charitable foundations in the USA, Arius is currently developing a strategic scoping project to interact with appropriate organizations and individuals from several countries, in order to assess their level of support for establishing formal multinational working groups tasked with preparing for the establishment of lasting, ERDO-like, regional organizations that will implement shared used fuel disposition facilities.

Initiating discussions at the appropriate political and technical level, involving the most relevant and concerned organizations, requires a stimulus that most national programmes have proved unable to spark-off themselves. Beginning with a European initiative was the simplest approach, since an overarching organizational structure (the EU) already exists. Arius has explored the feasibility of adapting and applying the ERDO model to other global regions and concluded that, of various possible areas worldwide, the regions that may show the most immediate promise and potential interest are the Arabian Gulf region and South-East Asia. This assessment is based principally on the advanced state of development of new nuclear infrastructure, the presence of active national nuclear power development programs and the geographical potential for sharing waste management solutions. The overall aim of this scoping project will be to assess the interest in working towards Regional Repository Development Organizations (RDOs) similar to the European ERDO in these regions. Other possible groupings in the future could include Central and South America, and Africa. We hope to implement this project later this year, and hope to have the collaboration of the IAEA in promoting the concept.

5. CONCLUSIONS

Waste disposal costs are not a major cost driver for large nuclear programmes, but for a country with just one or a few reactors, the multi-billion-dollar cost and substantial technical demands of establishing a national repository may be a substantial factor in decisions. Moreover, if the spread of nuclear energy production is to occur without increasing the risks of global terrorism and nuclear proliferation, there must be close international scrutiny of all nuclear activities [5]. This will be easier if all sensitive materials in the nuclear-fuel cycle are handled, stored, and disposed of at fewer locations. Shared disposal facilities for the spent fuel and highly radioactive wastes at the back end of the fuel cycle should be one key component in a secure global system.

Based upon experience in national programmes, there seems to be no reason why the difficult matter of finding sites for regional repositories cannot be resolved using a developed form of the volunteering approach, and a way forward on this front has been proposed. For all the much broader aspects of establishing a multinational repository development organization, the European ERDO is providing a practical example of what can be done that could be followed by other regions worldwide where countries see the clear benefits of sharing solutions, especially for those countries just setting out on the road to nuclear power. Repeating the mistakes of every existing nuclear power nation worldwide and leaving the waste issue for some unspecified future generation to sort out, is not a good starting point, and the IAEA has a key role to play in emphasising the importance of fully integrated nuclear power programmes.

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We would like to acknowledge the encouragement and input of all those individuals and organizations that have worked to ensure that the ERDO-WG came into being. Whilst the development of multinational solutions is widely acknowledged to be essential, making any real progress at all can be an uphill struggle into strong headwinds. We hope that this situation will change, with the example set by the ERDO-WG members.

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