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INFORMATION AND ANALYTICAL ENVIRONMENT OF THE RESEARCH PROGRAM FOR DEVELOPMENT RUSSIAN DEEP GEOLOGICAL REPOSITORY SAFETY CASE

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The subject of this paper is knowledge management issues of the Russian Deep Geological Repository Project. The paper describes the software environment being developed for the purposes of knowledge accumulation and systematization and subsequent application in the safety case and safety demonstration. Both the current status of software environment components and the prospects of their development are considered, as well as potential integration capabilities into the digital underground research laboratory concept within the context of stakeholders' requirements and modern technical opportunities.

Keywords: *radioactive waste, deep geological repository, digital underground research laboratory, safety case and safety assessment, knowledge management.*

Background

The problem of knowledge management, including information security and availability is one of the key research directions in international practice [1—4].

Respective studies [5] and actions are envisaged by the "Strategy of DRWDF development" [6] at all stages of project implementation (directions "Management system and human resources", "Research and development on safety case", "Interaction with stakeholders").

IAEA documents [7—9] underscore the importance of:

- availability, including availability to the future generations, of all information on the stages of DRWDF lifecycle (see, for example, it. 6.21 [9], it. 6.83 [8]);
- traceability, i.e. clear and complete documentation of the decisions and assumptions made, safety arguments, calculation models, parameters and data, expert assessments, etc. (see it. 4.98, 5.20, 7.16 [9]).

Structure of safety reports and various level of documents used by the French National Agency for Radioactive Waste Management (ANDRA) for justification of safety and feasibility of the RW geological disposal in clay formations [10] is given as an example in Fig. 1.

The current paper describes an information and analytical platform designed to support the safety case process for the Russian DRWDF — PULSE (Project of Underground Laboratory Scientific Escort, Project of URL scientific support). The knowledge database is the central and key element of the PULSE project.

PULSE shall combine the knowledge base, calculation codes implementing the integral long-term evolution model, as well as three-dimensional information and analytical model of DRWDF (Fig. 2).

The translation is done by V. I. Shpinkov

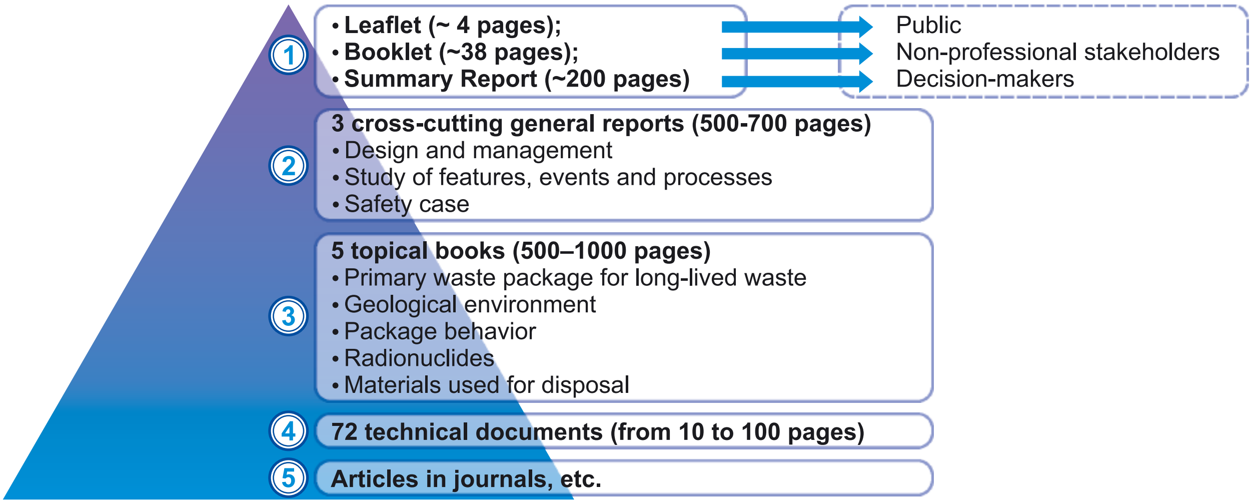

Fig. 1. Structure of ANDRA documentation for the project of RW geological disposal

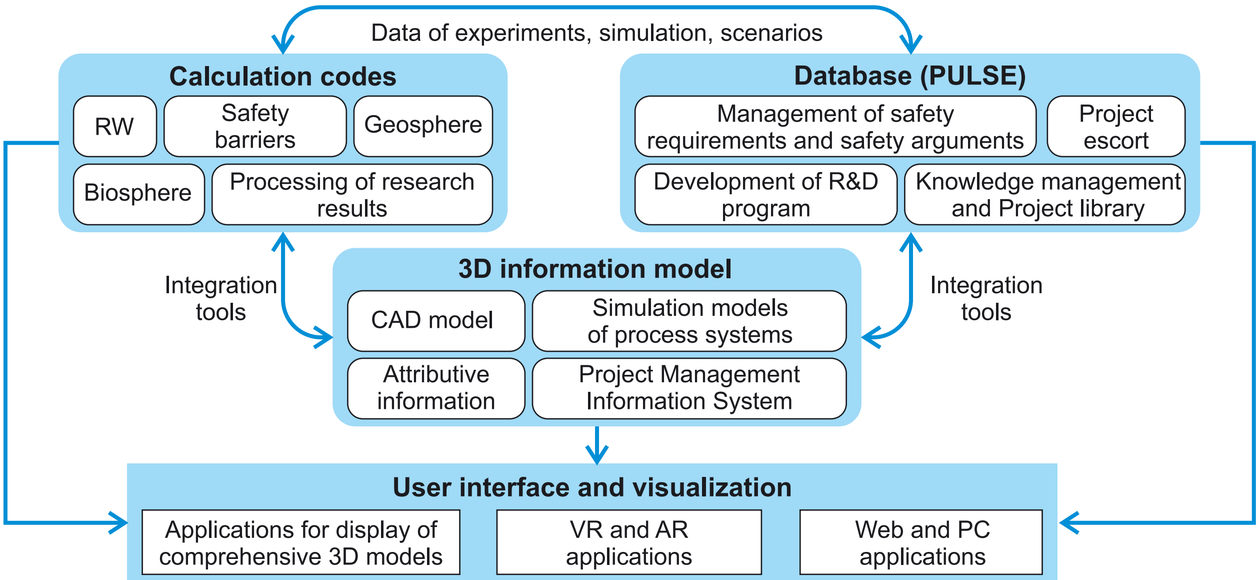

Fig. 2. Main elements of the Pulse project

Knowledge Database

In the light of the requirement of availability of the information covering DRWDF lifecycle, the basic element of PULSE knowledge database is a file archive containing all documents accumulated on the subject and used in process of safety case development:

- scientific, technical reports and overall documentation of the project over the period of its implementation (starting from mid-1980 – s);
- all relevant reference documentation, with volume exceeding the volume of the reports by many times;
- reports on overseas DRWDF projects;
- compilations of scientific publications on various aspects of RW disposal.

It should be noted that due to the attention paid to knowledge conservation in major projects [4], not necessarily connected to disposal of radioactive waste, there currently are international information systems publicly available, for example, library of documents covering all aspects of IAEA activities [11].

The developers of PULSE do not intend to duplicate these systems. All documents used in any way in the process of safety case development, either as argumentation, data source or any relevant information, are gradually added to the file archive.

The next step is transition from a structured information storage to a knowledge database, which requires implementation of tools for use of information in decision-making at various stages of implementation of the Strategy of DRWDF development. These tools shall process all the accumulated information, as well as information received as a result of actions performed or studies. Also there should be a capability to take into account and analyze expert opinions.

At the current stage of development, PULSE knowledge database contains the tools for the following tasks:

- systematization and analysis of the extent of implementation of requirements to the DRWDF based on various sources (section "LSR and requirements");
- justification of the most probable and alternative scenarios of disposal system evolution including connections with required research (section "LSR and requirements");
- structuring of the already carried out and planned studies, including their interconnections (section "Research program);
- analysis of the state of knowledge of the disposal systems in terms of Features, Events, Processes (section "Features, Events, Processes) [12];
- documentation of experts work in the framework of safety argumentation and project escort (section "Project Escort").

PULSE database is developed as a web interface for the Oracle database management system [13]. The interface provides options to display information in the form of various structured forms and graphs for organization of convenient work on analysis and modification of data. If required, access to specific tools may be granted or restricted for specific users or groups of users.

For example, IAEA documents contained in "LSR and requirements" section are decomposed into a system of separate requirements and recommendations [5], and may be viewed as a report with search and selection capabilities, and references to the full text. A similar structure is implemented for regulatory requirements regulating various stages of DRWDF lifecycle.

In contrast to the regulatory ones, the technical requirements to the components of the disposal system are formulated in process of development of the safety case for a specific facility.

Therefore, the user may interactively add or edit such requirements in terms of elements of the disposal systems, their functions and relevant characteristics. Such an approach was best described in a joint report by Finnish company Posiva and Swedish SKB [14].

The section "Features, Events, Processes", as in the case of requirements, has unchangeable external information and information which is modified and developed in a stepwise safety case process. Thus, FEP categories based on the international list of safety-relevant factors [12] and the factors considered in respective categories in the framework of overseas projects [5, 15] are "fixed", while a special form is implemented for analysis of specific FEP factors affecting the designed facility.

Development of the program of studies required for long-term safety case [5] is reflected in the section "Research program". Fig. 3 shows a high-level research matrix with studies grouped in accordance with the respective elements of the disposal system and types of activities. The colour of the cell at the intersection of the element and type of activity shows the number of connected studies and

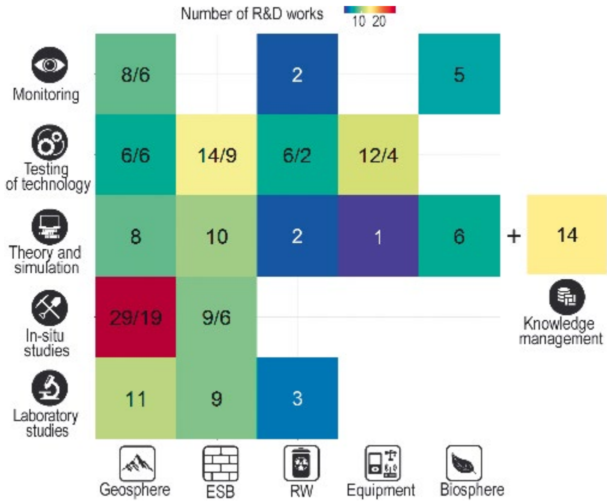

Fig. 3. Preliminary number of R&D studies in the framework of the Research program with regards to respective disposal system elements (horizontal axis) and types of activities (vertical axis)

the number after the slash "/" shows the number of studies in the underground research laboratory.

Each study in the Program shall have a filled-in study passport, which shall include the following information: studied element of the disposal system; research direction; code of work; name and goal; assumed starting date; basis for implementation; results of previous studies; equipment used and methods required for analysis; supposed results and its future use.

The following fields are also envisaged for studies at the URL: measured characteristics, in support of which disposal concept the experiment is carried out, requirements to localization and duration, materials and equipment.

R&D description will be enhanced and modified as the system is further developed.

As research reports are received they, as well as the results of expert analyses of requirements and FEPs, are systematized in a special knowledge database section defining the long-term safety case structure in accordance with IAEA requirements [9] and best international practices [16, 17] (Fig. 4).

Calculation codes as a part of integral model for the long-term safety case

The results of simulation of deep RW disposal facility evolution and its impact on human and environment in long-term outlook form a key element of the safety case (see section 5 [9]). Specific models of disposal system elements [18—21], as well as the integral model of long-term facility evolution shall reflect the current level of knowledge and cover all aspects of DRWDF long-term safety, including characteristics of ionizing radiation sources and their radiation fields, specific features of radionuclides leaching from various types of RW, interaction of various forms of radionuclides with engineered

LTSC Structure

- LTSC
  - Final Report
    - Description of safety concept
    - Definition of safety functions, relevant parameters and assessment criteria
    - Confirmation of safety functions implementation by research at URL
  - Set of general documents
    - Series of reports on initial conditions (input data reports)
      - Site condition
      - ESB condition
      - RW composition and parameters
    - Series of reports on internal processes
      - Report on processes in RW and in the matrix
      - Report on processes in the canister
      - Report on processes in the backfilling
      - Report on processes in the concrete
      - Report on processes in host rock (including EDZ)
    - Series of reports on external processes
      - Climate report
      - Geosphere report
    - FEP report
    - Final report on scenarios
    - Report on models used
    - Report on radionuclide transport
    - Report on long-term modeling results
    - Report on operation consequences
  - Additional information
    - Design documentation
    - Site description
    - R&D results, including earlier studies
    - FEP database

Fig. 4. Preliminary structure of long-term safety case

barriers and their near-field transport, features of interaction and contamination transportation in a geological environment, radionuclides transport in the biosphere and forecasted assessments of DRWDF radiation impact on population and biota, a system of auxiliary arguments required to raise the level of justification of calculations and trust in the project on the whole [9].

Exchange of data between the calculation codes is performed by formation and transfer of scenarios of change of material properties and processes — sets of parameter values assigned to specific time period of the calculation process. Sensitivity and indeterminacy estimates [22] are also essential as they may be one of quantitative criteria for selection and prioritization of further research, which may present results critical for design solutions ensuring long-term safety of DRWDF.

Information and analytical model of DRWDF

Three-dimensional information and analytical model based on Neosyntez platform [23] implements the requirement to conceptual description of DRWDF model, including data on the materials used and elements of the disposal system (it. II.27 [8]).

Such an approach to description and demonstration of design solution has found wide use in construction in the form of BIM (Building Information Modeling) and includes generation and management of digital images of physical and functional parameters of real objects. The systems are ranked in accordance with the completeness of information for dimensions:

- 3D — 3-dimensional facility model;
- 4D = 3D + time (process schedule, verification of design solutions in dynamic);
- 5D = 4D + cost (increase of efficiency, cost control);
- 6D = 5D + sustainability (sustainability, energy efficiency);
- 7D = 6D + management (facility lifecycle optimization).

The current goals of the information and analytical model — verification and feasibility demonstration of design and technical solution corresponds to the 4D level of BIM model. However, higher dimension levels will be required at future stages of DRWDF design.

One of the directions 4D modeling development is the use of combined THMBC (thermal, hydrodynamic, mechanical, biological and chemical) calculations. Results of these and other calculations would be verified in experimental studies at URL

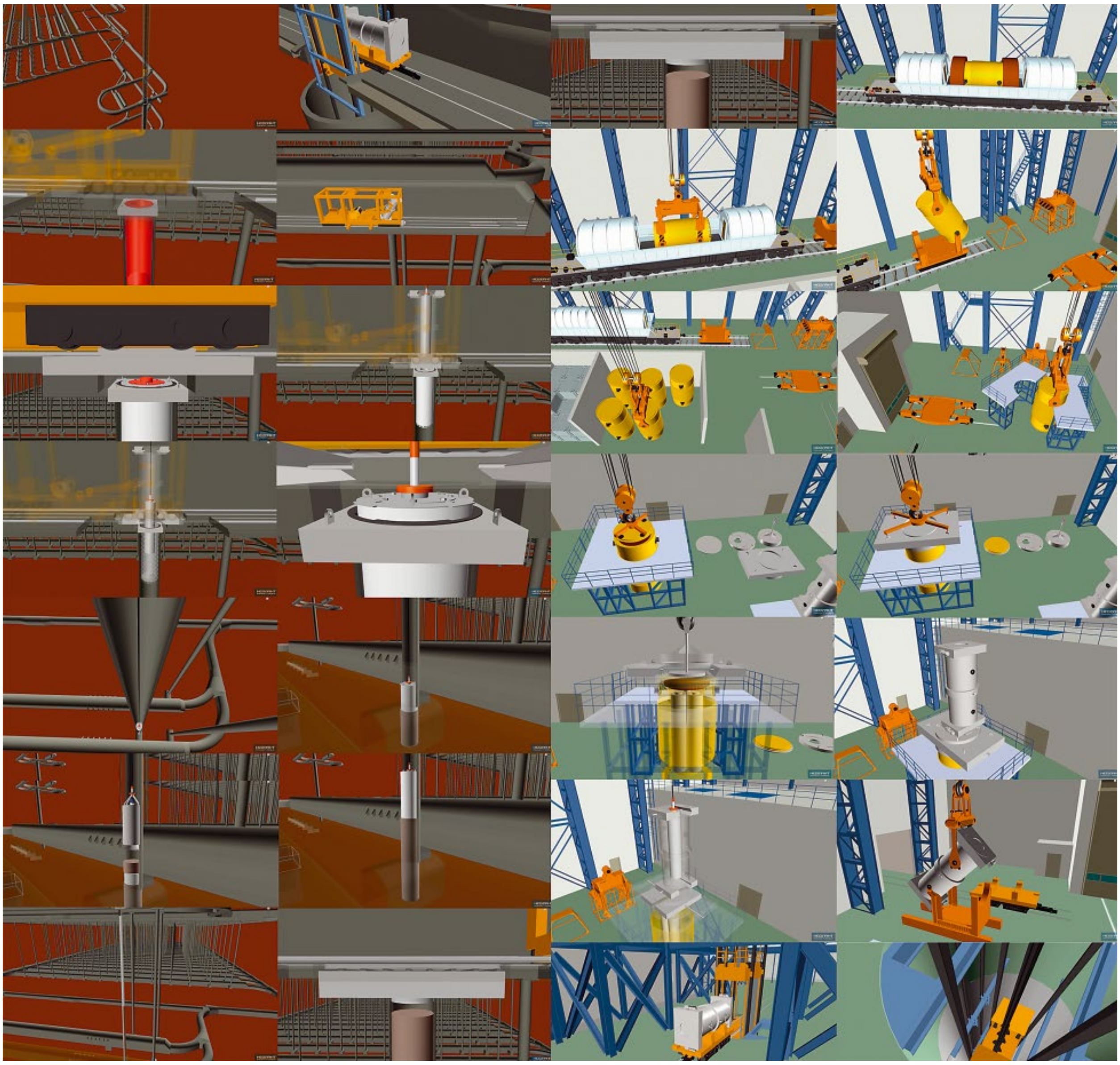

Fig. 5. Animation image of technological operations with 1 class RW

and would affect the parameters of facility layout, design and materials used for its elements, as well as process parameters.

Fig. 5 shows animation image of technological operations with 1 class RW as an example of a 4D process. Such an illustration shows the process in detail and allows identifying problems already at the design stage as all the elements of the future facility are included in the 3D model. If a dynamic process proves to be impossible in 4D, then changes are introduced either to the 3D model (e.g., borehole cross-section is increased to fit the container), or to the process (a different loading method is considered).

Integration capabilities and further development

The objective of the works at the current stage and the vector of further development of the information platform of DRWDF research is gradual integration of calculation and software system, accumulated arrays of data, design solutions and available technologies to the digital URL structure.

The purpose and potential of the digital URL is to provide the specialists with a relevant tool for study of the processes at the projected DRWDF using digital models based on the parameters of a specific facility, and to provide access to accumulated information. The relevant software shall, on one hand, analyze and display the processes taking place at the experimental facilities of the underground laboratory, and, on the other hand, effectively plan and control the design of the geological disposal system.

Visualization of the results of disposal system digital modeling should assist the specialists and help demonstrate the safety and will be a valuable tool for interaction with stakeholders.

Results produced by calculation codes, i.e. quantitative and qualitative safety and feasibility arguments based on mathematical modeling results (it. II.10 [8]), shall naturally be incorporated in the structure of the long-term safety case, however, the integration capabilities shall not be limited to that. Full-scale integration of calculation codes with the PULSE database will allow using the latest experimental data and plan numerical experiments required for confirmation of specific safety arguments.

Integration of software systems and the information and analytical model will provide additional information about the objects included in the 3D model. Reflection of the changes of this information with time will constitute the 4D level of BIM approach. Also analysis of international experience demonstrates that such a model may become an interface of the Project knowledge database. For example, the German VIRTUS project [24] includes implementation of a "virtual underground research laboratory", where one can while "moving" along the three-dimensional DRWDF model both receive historical information from the database and plan and conduct numerical studies.

The interface of the numerical underground laboratory will include both virtual reality (VR) and augmented reality (AR) elements. VR is a three-dimensional model which surrounds the user, and AR are the computer models visible for the user in the real world.

The VR and AR market is currently expanding rapidly and supplies the users with many technologies, which can be used in the framework of DRWDF research program. For the case of VR technology there are applications for URL personnel training and training of specific actions (direction "Practical works at the site" of the DRWDF development strategy [6]), and implementation of virtual excursions to the underground laboratory. Also such an application may be used for remote peer review of the current status of works. One of the options of implementation of AR-technology is information support (acquiring additional information about the URL elements and systems, navigation at the site). AR also allows display of the full scale 3D model with all experimental and calculation data using just a smartphone and special marker or any flat surface (table, stand, etc.). Such capabilities of VR and AR technologies may be both a tool for implementation of IAEA recommendations and an instrument of communication with stakeholders.

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Bibliographic description

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