ESTABLISHMENT OF AN OPERATIONAL SAFETY ASSESSMENT FRAMEWORK FOR A HIGH-LEVEL RADIOACTIVITE WASTE REPOSITORY

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In this study, we established the methodology and assessment framework for the operational safety of a high-level radioactive waste repository. The operational safety assessment consists of a systematic examination of the repository site and facility design, an evaluation of potential hazards, initiating events, event sequences, and an exposure assessment for workers and the public. The initiating events can be identified using an appropriate operational hazard analysis methodology such as hazard and operability study, and failure modes and effects analysis. We suggested a PSA (Probabilistic Safety Assessment) method for event sequence analysis that has the potential to cause radiological consequences to workers and the public. For the event tree and fault tree analysis, the AIMS-PSA (Advanced Information Management System for Probabilistic Safety Assessment) Manager and the sub-modules CONPAS (CONtainment Performance Analysis System) and KwTree (KIRAP window Tree) will be used. The consequence analysis for each event sequence is to calculate exposure doses to workers and the public. The RSAC (Radiological Safety Analysis Computer) program and the consequence analysis module in the SSAT (Systematic Safety Assessment Tool) program will be used in the estimation of exposure doses to the public and workers. We made sample calculation for the drop accident due to crane failure at the surface facility of the KRS (Korean Reference disposal System) in order to check the applicability of the operational safety assessment framework. We made four event sequences considering failure of fuel cladding breach, failure of primary HVAC system, and failure of primary HEPA filter. We estimated the exposure doses to workers and the public and found that they are far below the regulatory limits. We also developed a RAWR (Radioactive Waste Repository Reliability Database) program to support the operational safety of a radioactive waste repository. The methodologies and tools for the operational safety assessment of a radioactive waste repository established in this study can be used in the design modification as well as the operational safety assessment of a high-level radioactive waste repository.

I. OPERATIONAL SAFETY ASSESSMENT FRAMEWORK AND SAMPLE ANALYSES

The fundamental safety objective of a radioactive waste repository is to protect people and the environment from harmful effects of ionizing radiation by applying safe, practicable and environmentally acceptable solutions for long term management of radioactive wastes[1]. To ensure the public and worker safety, the safety assessment has to be performed to demonstrate that a geologic repository can be designed and operated in compliance with the performance objectives. The performance and safety of a waste repository is evaluated for two periods: pre-closure (operational) and post-closure. The operation period of a waste repository is the period before such a repository is permanently sealed. During the operation period, the radioactive waste may be handled at the surface and subsurface facilities for receiving, repackaging, transporting, and emplacing.

According to the general guidelines for deep geological disposal system for high-level radioactive wastes in Korea[2], the operational safety assessment has to be performed by considering the intrinsic characteristics of a repository and the general guidelines and criteria for nuclear installations. The PSA (Probabilistic Safety Assessment) methodology[3] has been used to assess the safety of a nuclear power plant in Korea. Also much research and development programs such as the development of a tool and establishment of reliability data, etc. have been made in KAERI (Korea Atomic Energy Research Institute). The PSA methodology is used as a tool not only for the safety assessment of NPPs (Nuclear Power Plants) but also for safety assessment of a radioactive waste repository, an interim spent fuel storage facility or other industry fields. Therefore, we suggested the PSA methodology to perform the operational safety assessment of a radioactive waste repository.

In this study, we established a framework for an operational safety assessment of a radioactive waste repository by establishing an analysis procedure and choosing necessary tools. And we checked the applicability of the established framework through a sample calculation for a drop accident at the surface facilities of the KRS (Korean Reference disposal System) which was developed as a repository for the disposal of spent nuclear fuels in Korea[4].

I.A. Establishment of an Operational Safety Assessment Framework

We made a procedure for the operational safety assessment of KRS, which is summarized in Fig. 1 (Ref. 5). This figure also includes the applicable fields of the safety assessment results. The procedure is similar to overall sequence and review methodology of operational safety assessment of a radioactive waste repository for YMP (Yucca Mountain Project) and pre-closure tool activities[6]. As shown in Fig. 1, the collection of information is required. First of all, site data refer primarily to meteorology, geology, and human activities around the site. The facility data include description and design details of structures, systems, and components of the repository. Also the characterization of waste and source terms and description of repository operation procedures with an adequate understanding of the component and facility functions and sequence of operations are necessary. These data will be constructed as database by referring to the reference sites and facilities and used as base data for fault tree and event tree analysis and dose calculation.

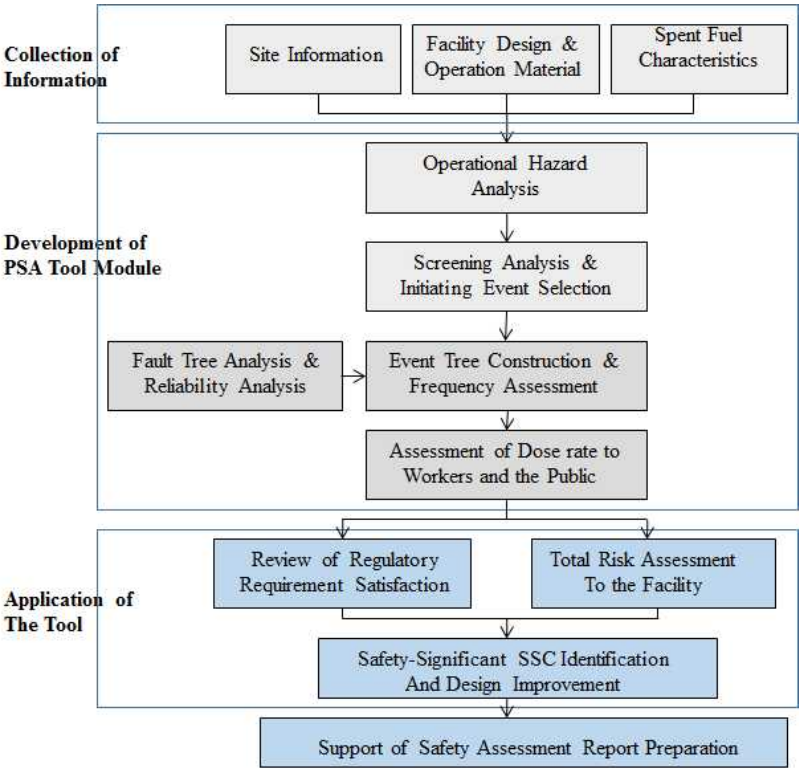

Fig. 1. Overall procedure of operational safety assessment of a waste repository.

The steps of operational safety assessment are established based on a review of the safety assessment procedures and methodologies which are used in other industries including a nuclear power plant. The procedures include (i) selection of initiating events through operational hazard analysis and screening analysis, (ii) event tree construction for each initiating event through ETA (event tree analysis) and estimation of failure probability by FTA (fault tree analysis), (iii) assessment of exposure dose to workers and the public using an appropriate tool.

The initiating event is defined as the event that can induce the collapse of the normal state and can create radioactive exposure to workers and the public. Usually, the initiating events for a nuclear power plant PSA are selected based on the various experiences. However, the initiating events are not common to PSA for a radioactive waste repository and they should be selected by considering the characteristics of the site and facility and operational procedures of the repository. Therefore, the initiating events can be selected using an appropriate operational hazard analysis method such as what-if Procedures, FMEA (Failure Mode and Effect Analysis) or HAZOP (HAZard and Operability) methodology and screening analyses.

We suggested the ETA methodology for an accident scenario analysis. Using ETA methodology, accident scenarios can be developed and the frequencies of each accident scenario that consequently induce release of radioactive material by considering the operability of safety systems to mitigate the accident can be estimated. FTA is used for the probability estimation of a mitigating system. CONPAS (CONtainment Performance Analysis System) was selected as a tool for ETA. CONPAS is included within AIMS-PSA (Advanced Information Management System for PSA) manager developed for the safety assessment of nuclear power plants by KAERI (Korea Atomic Energy Research Institute) (Ref. 7). FTA is applied to the failure probability evaluation of the system in the event tree. KwTree is selected as a tool for FTA. KwTree (KIRAP window Tree) is also included in the AIMS PSA Manager.

Consequence analysis is the module to estimate the exposure dose to workers and the public for accident scenarios inducing release of radioactive material. Exposure doses for workers and the public is estimated by considering the appropriate exposure pathways and dose coefficients. The result of consequence analysis will be provided with mean value and confidence interval for the probabilistic analysis. In addition, CCDF (Complementary Cumulative Distribution Function) form will be provided for convenience and application of the result analysis. Among the many programs, we selected RSAC (Radiological Safety Analysis Computer Program) (Ref. 8) for exposure dose analysis. Also, exposure doses to workers and the public can be estimated using the consequence analysis module in SSAT (Systematic Safety Analysis Tool) (Ref. 9). SSAT was developed for the safety analysis of a potential interim spent nuclear fuel storage facility. The consequence analysis module in SSAT was developed based on the RSAC program. However, the ingestion pathway is not considered. Therefore, it can be used for the estimation of exposure doses if the ingestion pathway is negligible. The resulting exposure dose rates to workers and the public can be compared with the regulatory limits to check the regulatory compliance. Figure 2 shows the main screen for each program which we chose, respectively.

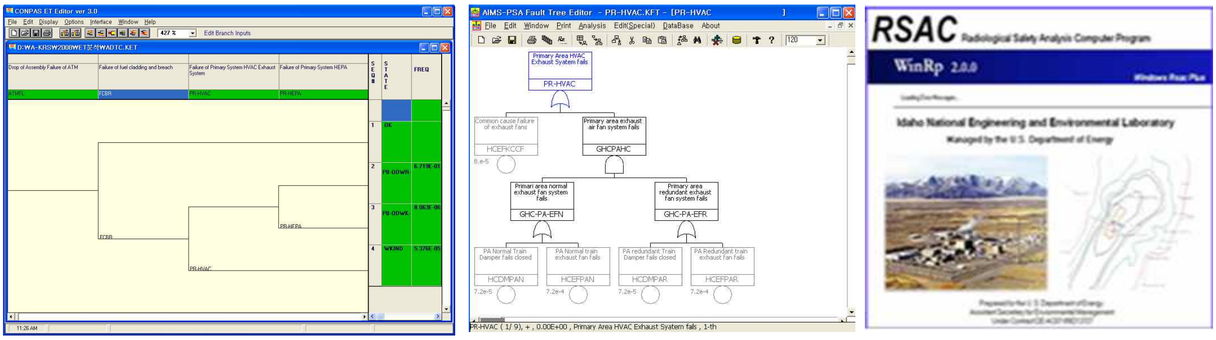

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Fig. 2. Computational framework for the operational safety assessment.

I.B. Example Analyses

We performed an example analysis for a drop accident at a surface facility of the KRS to check the applicability of the established operational safety assessment framework. According to the conceptual operation procedure of the KRS, the spent fuel assemblies will be transferred using a crane from the transportation cask to the waste package for disposal. The drop accident as an initiating event for illustrative analysis in this study is a drop of a spent fuel assembly due to a failure of the crane caused by mechanical, electrical, and control systems including human errors while transferring an assembly.

An example event tree for the drop of a spent fuel assembly is shown in Fig. 3. As shown in this event tree, a spent fuel assembly is dropped from the crane onto the surface of the encapsulation facility. After this initiating event, the spent fuel assemblies may breach, the HVAC (heating, ventilation, and air conditioning) system may fail to exhaust air from the transfer area, and the HEPA (High Efficiency Particulate Air) filtration may fail to operate.

As shown in Fig.2, there are four accident sequences for a drop accident. Accident sequence 1 results in no consequence because there is no fuel cladding breach. Accident sequence 2 may result in a noble gas release to the public and outdoor workers due the fuel cladding breach. Accident sequence 3 is that the fuel cladding is breached, and the HVAC system succeeds but the outdoor workers and the public are exposed to noble gas and radioactive material particles since HEPA the filter system fails. Finally, accident sequence 4 may result in noble gas and particulate releases to the worker in an adjacent room as a result of a loss of differential pressure caused by failure of the HVAC exhaust system.

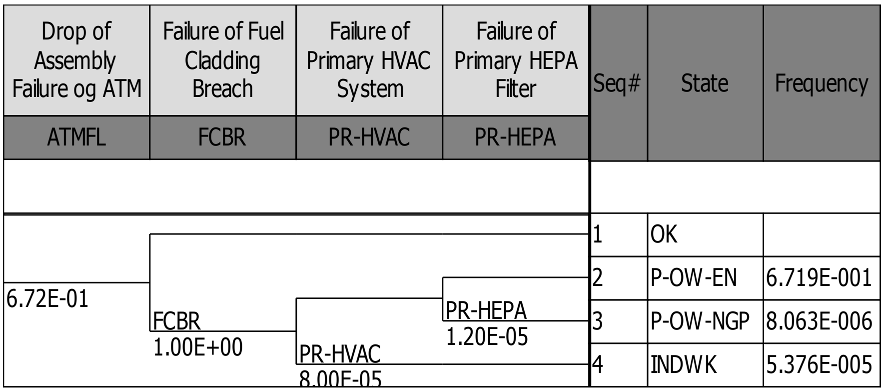

Fig. 3. Accident sequences for a drop accident.

The occurrence probability of a drop accident was derived from the multiplication of drop rate due to crane failure and the number of spent fuel assembly transfer per year. The drop rate due to crane failure was assumed to be $5.6\text{x}10^{-5}$ drops/lift, which was derived from the reference[9]. We assumed that the number of spent fuel assembly which may be transferred by crane in the encapsulation plant is 12,000/yr. Therefore, the probability of a drop accident due to a crane failure is $6.72\text{x}10^{-1}$ drops/yr. We assumed that the spent fuel cladding is breached for conservatism if the drop accident occurred.

We used the fault tree analysis method to obtain the failure probability of each branch in the event tree shown in Fig. 3. For FTA, we assumed that the HVAC system consists of a normal exhaust fan and a redundant exhaust fan, and the HEPA filter consists of two filters. The failure probabilities for the HVAC system HEPA filter system for mitigation of a drop accident are evaluated through the FTA. The failure probability of HVAC system and HEPA filter system is $8.0\text{x}10^{-5}$ and $1.2\text{x}10^{-5}$, respectively. The data for the FTA were derived from the references[10,11]. Fig 4 shows the fault trees for HVAC system and HEPA filter, respectively.

We used a core inventory data for a reference spent fuel of PWR to estimate the exposure doses. The assumed repository site for the estimation of exposure doses is Wolsong in Korea. The important meteorological data were derived from the recorded data for one year at Wolsong site. We assumed the ground release and did not consider precipitation by rainfall for conservatism. And the atmospheric stability class was assumed to be neutral, and plume rise was not considered in order to obtain conservative results. The deposition velocity was assumed to be 0.01 m/sec for noble gases and 0.001 m/sec for other elements, and no deposition was assumed to occur for the noble gases, and the average breathing rate was assumed to be $3.34\text{x}10^{-4}$ m^3/sec for the estimation of inhalation dose[12]. The exposure doses for workers and the public estimated by using the consequence analysis module in SSAT are plotted in Fig. 5. Also, the CCDF plots for exposure doses are plotted in Fig. 6. According to the results summarized in Table 1, the internal exposure pathways such as inhalation and ingestion pathways are dominant exposure pathways although exposure dose values are not accurate because of using many default input parameter values.

To support the operational safety assessment of a radioactive waste repository, we also developed a RAWR (Radioactive Waste Repository Reliability Database) program, which is shown in Fig. 6 (Ref. 13). By using this program, we can get, edit, search, and update necessary reliability data for the estimation of operational safety for a radioactive waste repository. However, the necessary reliability data are not gathered because the detailed design information for the surface and subsurface facilities are not available. If the detailed design information with necessary systems and components are available, necessary reliability data from various sources can be obtained and be used for the operational safety assessment of a radioactive waste repository.

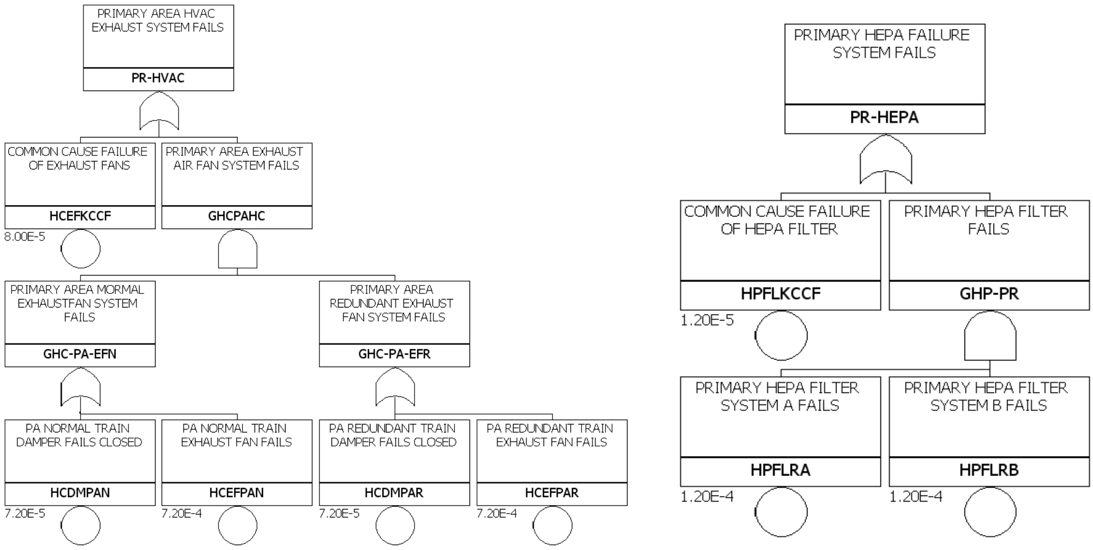

Fig. 4. Fault Tree for Primary HVAC System and HEPA Filter System.

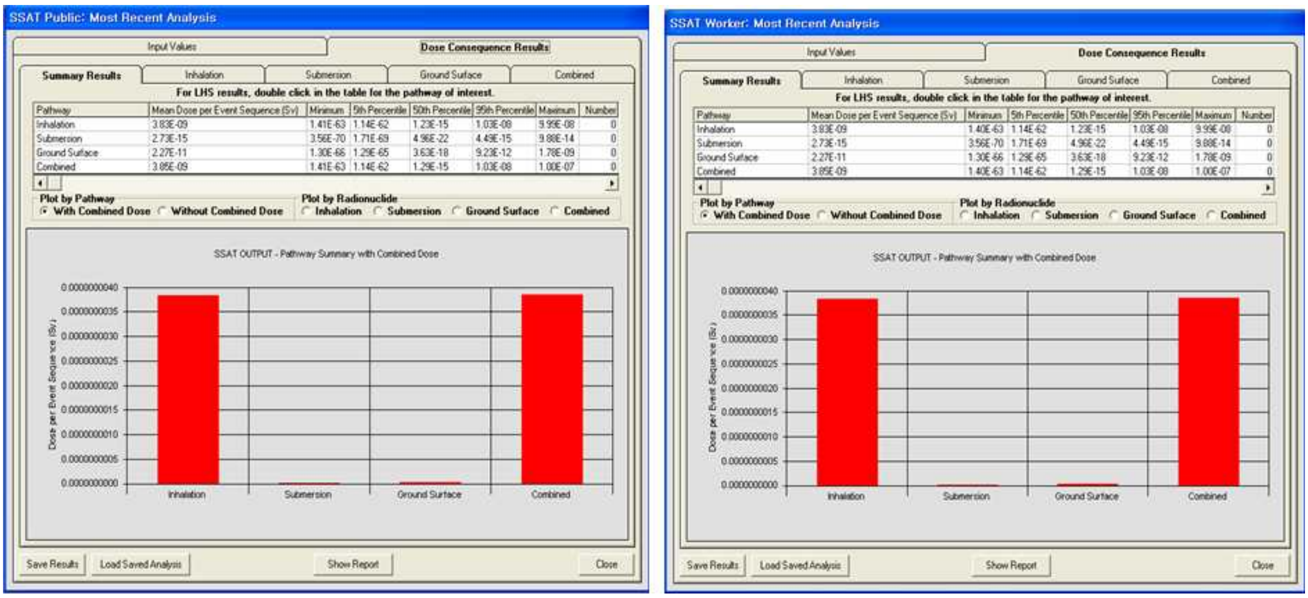

Fig. 5. Exposure dose for workers and the public for the drop accident of a fuel assembly.

II. CONCLUSIONS

We established an assessment framework for the operational safety of a radioactive waste repository using an AIMS-PSA Manager developed by KAERI and consequence analysis program such as RSAC. And we checked the applicability of the assessment framework by making an example analysis. We constructed an event tree for a drop accident of a spent fuel assembly due to crane failure and estimated the failure probability in each branch in the event tree, and then estimated exposure doses to the public for an event sequence. We found that the operational safety assessment framework established through this study can be a useful tool to evaluate the risk of a radioactive waste repository systematically. Also it can be used to design modification and improvement of a repository by performing importance analysis with the safety assessment result. Although the reliability database was developed to support the operational safety assessment of a radioactive waste repository, the necessary reliability data are not gathered due to the lack of detailed design information of surface and subsurface facilities of a repository. The assessment framework established through this study with necessary reliability data can be used to perform the operational safety assessment of a radioactive waste repository and the safety assessment of an interim storage facility of spent fuels.

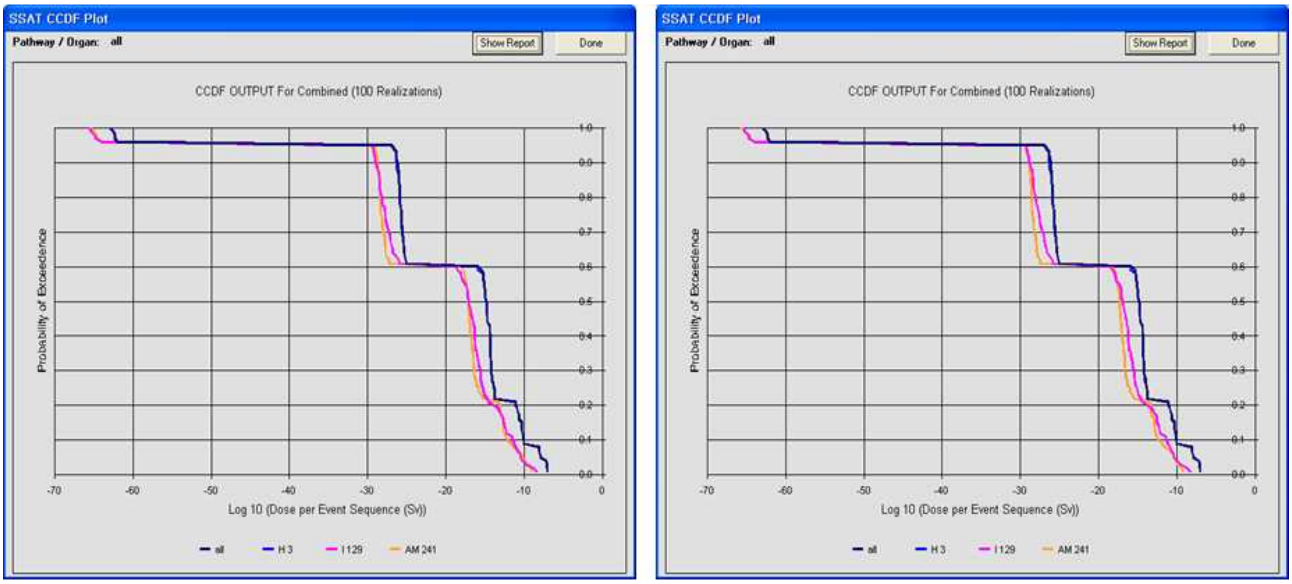

Fig. 6. CCDF plots of exposure dose for workers and the public.

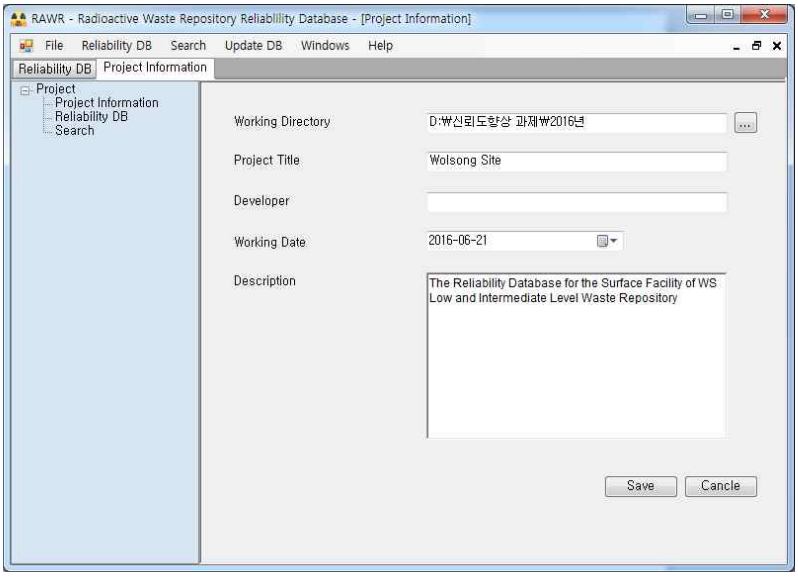

Fig. 7. Screenshot of the RAWR program.

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ACKNOWLEDGMENTS

This work was supported by the Nuclear Research and Development Program (No. 2012M2A8A5025589) of the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT and Future Planning (MSIP).

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