Chapter 8 Conclusions and future R&D requirements

In this Chapter, the results of the technical studies described in Chapters 2-7 are summarised and the future prospects for the implementation of TRU waste disposal, and the technological issues still to be addressed, are discussed.

8.1 Conclusions

(1) Generation and characteristics of TRU waste

In the 1st TRU progress report (TRU Coordination Team, 2000), the amount of waste generated during the period up to 2035 was calculated, but the calculation in this report now covers all the TRU waste generated in each facility of JAEA and JNFL during the entire operation period, in addition to dismantling (decommissioning) wastes generated after completion of reprocessing operations and wastes returned from BNGS. In consequence, the total amount of waste is estimated to be around 140,000 m^3 (approx. 700,000 x 200L drums)

The concentrations of radionuclides in the different waste types showed a wide range from 10^5 - 10^{12} Bq/t for α nuclides and 10^6 - 10^{14} Bq/t for β/γ nuclides. The classifications were based on the current upper limit of concentration for wastes generated by NPPs and it was confirmed that the wastes are suitable for deep geological disposal, intermediate-depth disposal or shallow disposal depending on their nuclide concentrations. It was estimated that around 26,600 m^3 of waste will be allocated for deep geological disposal, around 88,400 m^3 for shallow disposal (concrete vault) and around 25,200 m^3 for intermediate-depth disposal.

The characteristics of TRU waste are basically the same as those described in the 1st TRU progress report. The solidified wastes contain a wide range of materials, including cement and compressed metal components. In particular, waste intended for deep geological disposal contains iodine filter waste with a large proportion of I-129, hulls and ends and solidified wastes that include nitrates. Wastes for geological disposal were classified into four groups following the same logic as in the 1st TRU progress report (Group 1: iodine filters; Group 2: hulls and ends; Group 3: solidified wastes including nitrates; Group 4: other solid wastes).

Considering the thermal constraints for Group 2 in geological repository designs, excessive conservatism was eliminated and realistic values were derived. This was done by re-evaluating the amount of Co impurity, which contributes to the generation of Co-60 major nuclides during heat generation of hulls and end waste packages in the fuel assembly material and the neutron flux distribution in the reactor core,. In addition, hulls and ends include most of the C-14, which is considered to be a key nuclide from the point of view of safety assessment, and realistic values were also derived by re-evaluating C-14 in conjunction with the amount of nitrogen impurity in fuel assembly materials. The amounts of Co-60 and C-14 estimated to be generated are almost the same as those reported for overseas waste packages of hulls and ends and are therefore considered to be reasonable.

Based on the latest findings, the materials contained in the waste packages which are considered important from the point of view of safety assessment were quantified, including the amounts of organic materials in Group 2 and nitrates in the returned wastes from BNGS, which were not taken into account in the 1st TRU progress report.

(2) Evaluation of the geological disposal system

Based on the disposal concept described in the 1st TRU progress report, the various functions and specifications of the engineered barrier system were designed. In addition, based on detailed evaluations of heat production and the mechanical stability of disposal tunnels, basic specifications for the engineered barriers and disposal tunnels were prepared for the wide range of geological environments in Japan. Taking these specifications into account, a detailed evaluation of the long-term behaviour of the near-field was carried out. This considered the mechanical behaviour of the near-field, deformation of the engineered barriers, rock creep, thermal stress, variation in pore pressure due to gas generation and buffer material creep. The major components of the disposal tunnels were then refined. It is foreseen that safety assessments and the design of repository layout will be carried out iteratively. By adopting this approach, it is considered, for example, that the NO_3 leached from the Group 3 wastes can be prevented from affecting the emplacement tunnels containing other waste groups or the pathways by which the nuclides migrate from these wastes.

Furthermore, the prospects for implementing a repository are determined by considering the various stages of construction, operation and closure and presenting case examples from the latest engineering tests, the current status of technology and conceivable future developments of this technology.

For the safety assessment, phenomenon affecting the TRU waste repository was evaluated individually based on current knowledge. The aim was to understand the performance of the barrier materials and the temporal and spatial variations in phenomena in the environment surrounding the repository, and to reflect the setting of various conditions in the nuclide migration analysis. The phenomena evaluated included changes in cement and buffer materials, alteration of the host rock by a high-pH plume, radiation effects in disposal tunnels for Group 2, nitrates and organic materials and an analysis of the consequences of gas generation. The effects of colloids and microbes, which depend essentially on the conditions of the geological environment, were also evaluated based on existing knowledge. While maintaining a database on nuclide migration that reflects the evaluation of each of these phenomena including solubilities and sorption distribution coefficients, the data used in the H12 report, groundwater flow models and safety assessment scenarios were also reflected in the nuclide migration analysis. Deterministic consequence calculations were performed that considered the whole range of geological environments. In addition, a new statistical evaluation method was applied to evaluate the uncertainty of these models and

data/parameters and their combined effects.
The results of the Reference Case analysis showed that the maximum dose is ca. 2 μSv/y and is dominated by I-129, as shown in the 1st TRU progress report. Organic C-14 was the second most dominant nuclide. It was shown that effects on maximum dose are not significant under the geological conditions of the Reference Case. It was also shown that, in the case where the geological environment is less favorable than in the Reference Case from the point of view of groundwater mass transport, safety could still be assured by upgrading the nuclide retention performance of Group 1 waste packages to several tens of thousands of years.

The results for the perturbation scenario show dose values below 10 μSv/y in many cases. In the case where the formation of a new transport pathway due to drilling for natural resources, well drilling or water sampling was assumed, the maximum dose was ca. 100 μSv/y. However, these can be regarded as low probability phenomena and, using risk theory, it was considered that they could be assessed appropriately. There is also scope for taking into account engineering measures against the drilling scenario. For example, compartmentalization in disposal tunnels can limit the effects from the tunnels and reduce the dose. As an isolation failure scenario, uplift/erosion resulting in exposure of the disposal tunnels at ground surface and accidental penetration of the repository by drilling were evaluated. The effects of the former are smaller than those caused by drilling for natural resources. In the case of penetration by drilling, after dose conversion the risk is shown to be below 10^{-6} - 10^{-5} /y, which is the target safety standard in several overseas countries.

Based on concepts being studied in overseas countries, co-location disposal with high-level waste was evaluated as a major optimization design for the geological disposal system. Heat, alkaline elements, nitrates and organic matter have been identified as the key factors affecting interactions between the two disposal facilities. Knowledge of these interactions was summarised and the effect of the separation distance between the two disposal facilities was analysed. It was shown that interactions can be avoided by establishing a separation distance between the two disposal facilities of several 100 metres. Additionally, to establish the technology for co-location disposal, appropriate layout and engineering measures were evaluated.

In order to improve safety margins for a wide range of geological environments, research efforts aimed at eight advanced types of Group 1 solid waste forms and two types of Group 2 container waste forms were evaluated. This research relates to improving engineered barrier technology with a view to achieving nuclide retention times of several ten thousands of years. Additionally, in the assessment there are still outstanding concerns about the uncertainties connected with the alkaline alteration of bentonite and the effect on chemical potentials and activities. Low alkaline cement and nitrate salt analysis techniques are considered as potential measures for dealing with these effects on wastes containing bitumen and nitrate salts.

It is expected that, in the future, these alternative technologies will contribute significantly to improving confidence for the geological disposal of TRU waste. The validity and feasibility of these alternative technologies will be assessed from reviews of research and development relating to site-specific geological environments and improvement of confidence in various evaluations based on the reference disposal concept.

(3) Safety assessment of disposal systems near the surface and at intermediate depth

Safety assessments have been carried out for disposal of waste in near-surface concrete vaults or in intermediate-depth facilities. The evaluations used the upper concentration limits for waste generated from NPPs and the disposal concepts and safety assessment methods described in NSC progress reports (Nuclear Safety Commission of Japan). The parameters used in the evaluations were also taken from NSC progress reports. Additionally, assessments were made taking into account the engineered barrier similarity and the typically reducing environment in disposal systems at intermediate depth and near the surface, ranges of nuclide distribution coefficients and nuclide release rates from metal.

The maximum doses given by representative cases were in the range 10^{-4} - 10 μSv/y for both disposal systems, suggesting that safety can be assured. The dominant nuclide was Sr-90 in the population scenario for concrete vault disposal and C-14 in both disposal concepts for the groundwater scenario.

(4) Evaluation of optimisation disposal system (excluding co-location disposal)

Upper limits of radionuclide concentration for TRU wastes were estimated for both concrete vault disposal and intermediate-depth disposal. In addition, a classification based on the concentration of α nuclides in waste for intermediate-depth disposal was undertaken.

Upper radionuclide concentration limits for TRU wastes were estimated in accordance with standard methods used in wastes for NPPs. 100 GBq/t was obtained as an α nuclide concentration cut-off from trial calculations using several methods based on risk theory. At the same time, the volume of waste for intermediate-depth disposal increased from around 25,200 m^3 in the case where the classification criterion was 1 GBq/t for α nuclides to around 39,300 m^3. Similarly, the volume of waste for deep geological disposal decreased from around 26,600 m^3 to 12,500 m^3. The quantity of α nuclides in the waste for intermediate-depth disposal increased from 2.5×10^{13} Bq in the case where the cut-off was 1 GBq/t for α nuclides to 4.8×10^{14} Bq. However, concentrations of β and γ nuclide increased by only small amounts, from 4.6×10^{18} Bq to 4.8×10^{18} Bq. Based on this classification, there is only a trivial effect on the dose in safety assessment for disposal at intermediate depth.

Concerning the wastes that will be returned from overseas reprocessing, if a new method for returning waste that has been proposed by BNGS and COGEMA is adopted, there will be a marked reduction in the volume of material. Extensive optimization can be undertaken so as to decrease overseas transportation and upgrade the arrangement of the disposal facility.

The 2nd TRU progress report covers the refinement of assessments connected with the waste database, repository design and safety assessment. The report presents the results of a combined evaluation of optimization and alternative technologies demonstrates confidence in the prospects for establishing technology for optimizing the safe disposal of the waste.

It is considered that the results can be used as a technological basis for future disposal operations, safety regulations and assessment standards.

8.2 Future prospects for repository implementation

Establishment of safety and an optimum disposal system for TRU wastes is necessary to progress the utilization of nuclear energy and the nuclear cycle. This is considered to be an obligation for the current generation who benefit from nuclear energy.

Based on the results presented in the 2nd TRU progress report, evaluations were carried out of the future development of TRU waste disposal operations and the establishment of the institutional framework, taking into consideration the requirements and expectations of the electric power utilities.

(1) Deep geological disposal

According to Chapter 2-4 and 7, the safe deep geological disposal system of TRU waste were shown. In Section 6.2, it was suggested that co-location disposal with HLW waste would be effective considering the optimization of TRU waste disposal. For TRU waste from overseas reprocessing, the exchanged method between TRU waste and HLW from BNGS and changes of bituminized waste to vitrified low-level liquid waste from AREVA (COGEMA) were evaluated in Section 6.4 and it was shown that these methods would be effective.

From these results, it is expected that the development of the required institutional framework for implementing disposal operations will take place in the near future. It is also expected that the wastes which are returned as high-level waste or waste for deep geological disposal will be included in the current high-level waste disposal operations.

For the implementation of these disposal operations, it is important to promote future technological developments as described in Section 8.3 below and to ensure a sound technical basis for implementation of the disposal plan in Japan.

(2) Shallow and intermediate-depth disposal

In Chapter 5, wastes for shallow (concrete vault) disposal and intermediate-depth disposal were classified based on the upper limit of concentration for wastes generated from reactors, and safety assessments were performed for each type of disposal. Safe disposal could be demonstrated. Evaluations of the upper limit of concentration and α nuclide concentration for each disposal method for TRU waste were performed in Section 6.3. Based on this knowledge, it is expected that evaluations of the required standards in reprocessing facilities will be carried out and that developments of government ordinances/guidelines will be undertaken. In addition, these developments should be consistent with evaluations of safety regulations and technical standards for radioactive wastes generated from reactor facilities.

It is essential to consider establishing an implementing body and an implementation procedure at a national level. This approach will ensure the integrated development of the institutional framework and plans aimed at promoting disposal operations rationally and consistently throughout Japan. It is also essential to ensure the collaboration of related agencies, with the full understanding of the general public in Japan. Continued cooperation and the sharing of roles between the electric power utilities and JAEA is also required.

8.3 Future R&D requierements

In this section, the research and development results summarized in the 2nd TRU progress report and key issues for future technical developments are considered in order to secure the technical basis for disposal operations.

Both intermediate-depth and deep geological disposal systems are likely to have many common characteristics: large cavities, a cement-bentonite-based engineered barrier system, a reducing groundwater condition, etc. Therefore it is appropriate to consider future issues for technical developments related to the TRU waste disposal system focusing on issues relevant to a deep geological disposal.

In the areas of the geological environment, disposal technology and performance assessment, technical developments relating to the deep geological disposal system have been implemented using results and knowledge accumulated in connection with deep geological disposal of high-level waste. In order to promote technological development, it is important to address issues common to both disposal systems, as well as to the issues which are specific to the TRU waste disposal system. Furthermore, from the point of view of improving the reliability of co-location disposal and optimization of both systems, it is important for research and development on TRU waste disposal to be integrated more efficiently with research and development on high-level waste disposal.

Issues for technical development are classified into two main categories: fundamental research and development and development of implementation technology.

Fundamental research and development provides the basis for future disposal operations and for the establishment of safety regulations. Individual research and development activities summarized in the 2nd TRU progress report have two main purposes:

- Expanding knowledge by improving the assessment methodology
- Verification of its applicability to site-specific geological environments

It is planned that research and development will be performed using existing laboratory test facilities such as the Geological Isolation Basic Research Facility (ENTRY), the Quantitative Assessment Radionuclide Migration Experimental Facility (QUALITY) and underground research laboratories in domestic and overseas organisations.

In preparation for disposal operations, implementation strategies should be further optimised and refined in accordance with each step of future institutional development and site selection.

As examples of fundamental research and development, a waste database is shown in Table 8.3-1 and disposal technology in Table 8.3-2; performance assessment is shown in Table 8.3-3 and alternative technologies in Table 8.3-4. For each aspect of technical development, relevant issues, intended results, overlap with issues in both high-level waste disposal (HLW in the tables) and intermediate-depth disposal and facilities in which technical developments are performed are summarized. Concerning intended timescales, items to be implemented based primarily on fundamental research are shown as issues which should be implemented in the next five years and items to be implemented in accordance with the progress of site selection, etc. are shown as issues which should be implemented in accordance with stepwise progress.

The design methods and construction technologies necessary for implementation are shown in Tables 8.3-5 and 8.3-6 respectively. The tables are summarized in the same way as for fundamental research and development. With a view to implementation, performance assessments should include an understanding of site-specific phenomena, demonstration of evaluation models and understanding of uncertainty. Basically, these are seen as an extension of the issues described in fundamental research and development.

In the future, JAEA will check all wastes independently and this will improve knowledge of both detailed waste inventories and their uncertainties. TRU waste will also be generated from private reprocessing facilities and MOX fuel fabrication facilities in the near future. Based on the accumulated information on wastes, it is important to carry out a detailed design of the repository and develop detailed safety assessments in order to bring forward disposal operations.

At present, the processing technologies to be applied to TRU waste have not yet been determined. Based on the results of the 2nd TRU progress report, it is important to establish optimum measures for all processing and disposal operations of TRU waste.

Table 8.3-1 Fundamental research and development (waste database)

Item	Issue	Content	Time	Overlap with other wastes
Database develop-ment	*Acquisition of data on production rate, characteristics and activity of wastes	-Specification/expansion of the waste inventory in terms of production rate, characteristics, etc. of actual wastes -Acquisition/expansion of data on the amount of radioactive materials in actual wastes -Acquisition/expansion of data on the migration rate of nuclides waste (e.g. hulls and ends) and fuel coatings on waste -Selection of critical nuclides based on data on the amount of radioactive materials in wastes	(ii)	All other wastes
Waste validation method	*Development of methods for assessing the amount of radioactive materials in waste	-Development of non-destructive methods for measuring the properties of TRU waste -Development of new techniques for measuring radioactive materials that are difficult to measure.	(ii)	All other wastes

* Included in planned laboratory experiments in ENTRY, QUALITY and external facilities

(**) Included in the research and development plan in domestic and international underground research laboratories

(i): Should be implemented in next five years

(ii): Should be implemented in accordance with a stepwise approach in projects

Table 8.3-2 Fundamental research and development (disposal technology)

Item	Issue	Content	Time	Overlap
Under-standing the long-term behaviour of individual barriers	*Expansion of knowledge on the variation in mechanical properties of cementitious materials	-Testing and evaluating the effects of Ca leaching, aggregate/transition zone, corrosion expansion of steel materials and cracks, etc. on mechanical properties	(i)	Reactor waste
	*(**)Expansion of knowledge on the variation in mechanical properties of bentonite materials	-Expanding knowledge of mechanical properties associated with the alteration of minerals in various groundwater environments -Full-scale verification testing of the effects of construction, construction quality and heterogeneous swelling of bentonite	(i)	HLW & reactor waste
	*Expansion of knowledge on the effects of corrosion of steel materials (wastes, steel structural framework)	-Expanding knowledge of the corrosion behaviour of steel materials in high-pH, seawater and nitrate environments, and evaluation of corrosion expansion behaviour and mechanical stability	(i)	HLW & reactor waste
	*(**)Expansion of knowledge on the variation in mechanical properties of rocks	-Expanding knowledge of representative rock types in relation to mechanical properties associated with mineral alterations due to high pH, etc. -Understanding in-situ mechanical properties, taking into account site heterogeneities and effects of tunnel excavation	(i)	HLW & reactor waste
	*(**)Expansion of knowledge on creep behaviour of rock	-Determination of creep characteristics of representative rock types, validation and verification of evaluation models	(i)	HLW & reactor waste
	(**)Expansion of knowledge on the formation and variation of the excavation disturbed zone (EDZ)	-Acquisition of data on the formation of the EDZ associated with large-scale tunnel excavation, extent of EDZ, long-term evolution and development of evaluation models	(i)	HLW & reactor waste
Improving evaluation methodol-ogies	*Validation of deformation models of bentonite and cementitious materials	-Validation of long-term mechanical behaviour in the repository environment -Confirmation of applicability of constitutive equations based on simulations of the results of verification experiments -Validation and verification of models of the coexistence of bentonite and cementitious materials	(i)	Reactor waste
	-Improving the reliability of evaluation methods for the long-term mechanical behaviour of the near-field	-Upgrading evaluation methods for coupled deformation behaviour caused by rock creep, swelling pressure of bentonite, changes in characteristics of bentonite/cement -Establishing an improved evaluation method that integrates individual analysis models and long-term mechanical behaviour models	(i)	Reactor waste
	*Confirming methods for evaluating mechanical stability of the near-field with respect to gas generation	-Validation of methods used to evaluate long-term effects on mechanical properties of the near-field due to gas generation	(ii)	Reactor waste
	-Development of methods for evaluating the mechanical stability of the near-field during earthquake motion after repository closure	-Establishment of methods for evaluating the effects of earthquake motion after repository closure -Setting basic earthquake ground motion, definition of evaluation criteria, evaluation of changes in near-field conditions	(ii)	HLW & reactor waste
	(**)Validation of methods used to evaluate the long-term mechanical behaviour of the near-field	-Validation of methods used for evaluating in situ mechanical behaviour over the long-term -Evaluation of the behaviour of buffer material during saturation and evaluation of the behaviour of the engineered barriers during alteration	(ii)	HLW & reactor waste

* Included in planned laboratory experiments in ENTRY, QUALITY and external facilities

(**) Included in the research and development plan in domestic and international underground research laboratories

(i): Should be implemented in next five years

(ii): Should be implemented in accordance with a stepwise approach in projects

Table 8.3-3 Fundamental research and development (performance assessment (1/2)) (continued on next page)

Item	Issue	Content	Time	Overlap
Long-term behaviour of disposal system	*Expansion of thermodynamic data and reaction rates and analyses used to evaluate these data	-Expansion of knowledge aimed at reducing uncertainty in the thermodynamic datasets used for geochemical calculations -Expansion of knowledge on reaction rates and actual analyses taking into account kinetics	(i)	HLW & reactor waste
	*Expansion of knowledge on the changes in barrier characteristics that may occur during alteration, including alteration of cementitious material and bentonite, taking into account a range of chemical environments and barrier specifications	-Expansion of knowledge on alteration behaviour of cement-bentonite, taking into account a range of groundwater compositions and the specifications of engineered barriers, such as types of bentonite and cement, and changes in barrier characteristics that may occur during alteration	(i)	HLW & reactor waste
		-Improving chemical models that are appropriate for realistic environments, such as different levels of compaction or ionic strength	(ii)	
	*Clarification of the radiolysis mechanism of actual pore water	-Expansion of knowledge on the effects of coexisting components on the radiolysis mechanism of water -Acquisition of G values of radiolysis products in actual pore water	(i)	HLW & reactor waste
	-Setting realistic start times for nuclide leaching and elimination of initial transient phenomena from the scenario	-Realistic evaluation of confinement performance of waste (technical waste standards) -Realistic evaluation of resaturation	(i)	Reactor waste
	-Construction of logical approaches for development of scenarios	-Associating comprehensive FEPs with case scenarios deductively/inductively	(i)	HLW & reactor waste
Individual phenomena concerning nuclide migration	*(**)-Evaluation of groundwater flow rates in the excavation disturbed zone, taking into account heterogeneities in host rocks	-Development and improvement of evaluation methodologies for groundwater flow rates in the EDZ in various rock types -Development of methods for reflecting the effects of heterogeneities in host rocks on groundwater flow rates in the EDZ -Evaluation of applicability of these methods based on progress in hydrogeological research at Tono and Horonobe, focusing on characteristics specific to TRU waste	(i)	HLW
	*Expansion of knowledge for interaction between organic matter and oxidizing salts and for interactions between barrier materials of decay products and nuclides	-Evaluation of the promotion of oxidation-reduction reactions between bitumen and oxidizing chemical species derived from nitrate salt caused by the catalytic action of microbes	(i)	Reactor waste
		-Expansion of knowledge on the degradation of organic matter and the interaction between barrier materials and nuclides	(ii)	
	*(**)Clarification of the effects of microbe metabolism (decomposition of bitumen, $^{14}CH_4$ generation, etc.) and evaluation of the effects of metabolites (formation of complexing agents and colloids, etc.)	-Clarification of a metabolism scheme and establishment/development of a method for evaluating microbial effects	(i)	HLW & reactor waste
		-Evaluation of microbial effects in specific geological environments	(ii)	
	*(**)Classification of rocks in the light of alkaline alteration and establishment of alternative scenarios; expansion of knowledge on effects on mass transport characteristics of rocks due to alkaline alteration	-Classification of the widely distributed mineral composition of rocks and construction of alteration scenarios -Acquisition of mass transport characteristic for a medium in which alkaline alteration occurs and evaluation of changes in physical characteristics such as void structure, taking into account long-term mechanical behaviour	(i)	HLW & reactor waste
		-Evaluation and verification of effects of alkaline conditions in specific geological media	(ii)	
	*Improving evaluation of alkaline effects, taking into account the migration pathway characteristics of rocks (especially fractured media)	-Evaluation of alkaline alteration in a fractured medium, taking into account geological heterogeneity	(i)	
		-Expansion of knowledge on the filling of fractures and changes in the matrix characteristics of rocks		
	*(**)Refinement of evaluation methods for possible generation of colloids in specific geological environments	-Clarification of the conditions under which colloids are generated in groundwater in the vicinity of a repository affected by chemical perturbations	(ii)	HLW & reactor waste
		-Research into characteristics of colloids (concentration, types, etc.) in underground rock laboratories		
	*Expansion of knowledge on the chemical transition process of nitrates in geological media and refinement of evaluation of the area influenced by nitrates	-Expansion of knowledge concerning changes in the chemical forms of NO_3^- in geological media and the effects on groundwater quality and on nuclide oxidation state	(i)	Reactor waste
		-Evaluation of nitrate plumes, taking into account chemical transition processes of NO_3 in geological media		
	*Expansion of knowledge on the effects on nuclide migration parameters caused by high ionic strength due to nitrates	-Acquisition of nuclide solubility data and sorption distribution coefficient of nuclides in solutions with high concentrations of $NaNO_3$ and clarification of the concentration affected by nitrates	(i)	Reactor waste

	*(**)Acquisition of long-term data on gas generation rates, upgrading of gas migration models for clay materials and acquisition of migration characteristics	-Evaluation of models of long-term gas generation due to metal corrosion and microbial action and acquisition of relevant data -Development of models coupling gas migration with stress in clay media and acquisition of characteristics of clay materials by gas permeation tests	(ii)	HLW & reactor waste
	*(**)Development of gas migration models in fractured host rocks and validation of models; acquisition of migration data	-Development of gas migration models in fractured media and acquisition of data on migration characteristics of rocks and cementitious materials by gas permeation tests -Validation by comparing results of in-situ experiments with those of gas migration models -Considering a method for evaluating the effects on long-term mechanical stability	(ii)	HLW & reactor waste
	-Expansion of knowledge on radioactive gas generation	-Considering a method for evaluating the amount of radioactive gas generation and acquisition of relevant data	(ii)	Reactor waste

* Included in planned laboratory experiments in ENTRY, QUALITY and external facilities

(**) Included in the research and development plan in domestic and international underground research laboratories

(i): Should be implemented in next five years

(ii): Should be implemented in accordance with a stepwise approach in projects

Table 8.3-3 Fundamental research and development (performance assessment (2/2)) (continued on next page)

Item	Issue	Content	Time	Overlap
Nuclide migration parameters	*Acquisition of long-term data on C-14 emitted from activated metal	-Acquisition of reliable data on C-14 by long-term leach testing	(i)	Reactor waste
	*Acquisition of sorption distribution coefficients of organic C-14	-Selection and standardization of test methods, taking into account the stability of organic C-14, and acquisition of relevant data	(i)	Reactor waste
	*Understanding sorption/desorption behaviour of nuclides on colloids and expansion of datasets	-Acquisition of nuclide sorption distribution coefficients and sorption kinetic data for all types of colloids	(i)	HLW & reactor waste
	(**)Evaluation of the validity of methods for selecting nuclide migration distances and migration rates in groundwater	-Development of specific methods for selecting nuclide migration distances and migration rates in actual geological strata	(i)	HLW
		-Evaluation of applicability of these methods based on progress in hydrogeological research at Tono and Horonobe, taking into account characteristics specific to TRU waste		
	-Evaluation of applicability of sorption distribution coefficients obtained by batch methods to nuclide migration assessments	-Evaluation of applicability of methods for selecting sorption distribution coefficients obtained by batch methods to nuclide migration parameters	(i)	HLW & reactor waste
		-Evaluation of relevance of using chemical analogues		
	*Development of nuclide migration parameters corresponding to alteration behaviour of engineered barriers and rock, taking into account chemical environments and specifications of barrier materials	-Validation of thermodynamic data for nuclides under highly alkaline conditions	(i)	Reactor waste
		-Acquisition of sorption distribution coefficients and diffusion coefficients of nuclides, taking into account various groundwater environments and specifications of each barrier material and its variation		
		-Acquisition of nuclide datasets determined by chemical analogues		
	*Expansion of nuclide migration data under conditions which take into account chemical perturbations such as organics and nitrates	-Acquisition/development of complex formation constants of soluble organics and nuclides	(i)	Reactor waste
		-Acquisition/development of complex formation constants of nuclides, NO_3^- and NH_3, etc.		
	*Evaluation of chemical forms of C-14 in disposal environments and long-term variation of organic C-14	-Evaluation of release mechanisms of C-14 from activated metal (hulls, etc.) and evaluation of the chemical form of C-14	(i)	Reactor waste
		-Evaluation of morphological changes (mineralization) of organic C-14 in the disposal environment		
	-Expansion of data for the biosphere evaluation	-Development of data for C-14, Cl-36 and I-129, etc.	(i)	Reactor waste
Evaluation of system perform-ance	-Improving the reliability of nuclide migration evaluation methods for transitional conditions just after closure of the repository	-Expansion of knowledge on individual phenomena just after closure of the repository and variation of parameters associated with the evaluation; upgrading of conceptual and analytical models of nuclide migration	(i)	HLW & reactor waste
	-Improving the reliability of nuclide migration evaluations corresponding to the long-term behaviour of the near-field	-Expansion of knowledge on the variation of nuclide migration parameters associated with long-term behaviour of the engineered barriers and upgrading of both conceptual and analytical models of nuclide migration	(i)	HLW & reactor waste
	-Upgrading of analytical models reflecting knowledge of individual phenomena in alternative cases and uncertainty analysis	-Upgrading of conceptual and analytical models in alternative cases and in the uncertainty analysis	(i)	HLW & reactor waste
		-Evaluation of methods for setting appropriate data ranges in alternative cases and in the uncertainty analysis		
	-Evaluation of the uncertainty analysis, taking into account the correlation between nuclide migration parameters	-Evaluation of correlation of nuclide migration parameters	(i)	
		-Considering methods for evaluating the effects of uncertainty due to lack of information and sensitivity analysis methods		
	-Establishment of a formal approach (evaluation methods for scenarios, biosphere, etc.) in the alternative scenario and the human intrusion scenario taking into account the characteristics specific to Japan	-Combining features common to other countries with those specific to Japan	(ii)	HLW & reactor waste
	*Application of C-14 biosphere circulation model to safety assessment	-Evaluation of the applicability of the C-14 biosphere model to safety assessment	(i)	Reactor waste
		-Establishment of safety assessments taking into account the C-14 biosphere model	(ii)	Reactor waste

Safety assessment for co-location disposal	*(**)Criteria assessment of consequence factors	-Optimization and quantitative knowledge on the effects of nitrates, etc. on physical and chemical characteristics of individual barriers in the high-level waste disposal system	(i)	
	*(**)Evaluation of system performance conditions for avoiding interaction effects	-Evaluation of temporal-spatial behaviour of each effect, taking into account the geological environment and its heterogeneity -Understanding effects of engineered measures (plugs, etc.)	(i)	

* Included in planned laboratory experiments in ENTRY, QUALITY and external facilities

(**) Included in the research and development plan in domestic and international underground research laboratories

(i): Should be implemented in next five years

(ii): Should be implemented in accordance with a stepwise approach in projects

Table 8.3-4 Fundamental research and development (alternative technologies)

Item	Issue	Content	Time	Overlap
I-129 Immobilisation	*Validation of iodine release model	-Long-term immersion experiments under repository conditions	(i)	
	*Development of treatment processes	-Acquisition of process data (cold), recovery rates of iodine, equipment design/development	(i)	
	*Evaluation of disposal concepts for Group 1 in cases where alternative technologies are adopted	-Optimized design of disposal concept for Group 1 associated with adopting alternative technology	(i)	
	*Engineering-scale experiments based on a practical approach	Evaluation of properties, performance and throughput (processing) capacity of solidified waste	(ii)	
	*Performance validation of solidified wastes using actual wastes	-Performance validation for solidified wastes using actual wastes	(ii)	
C-14 long-term confinement technology	*Development of predictive models for assessing the long-term integrity of confinement-type containers (evaluation of long-term behaviour such as formation of cracks, processing effects, etc.)	-Modeling of occurrence/development/sealing of cracks after repository closure; validation and verification	(i)	Reactor waste
		-Processing of metal containers and evaluation of long-term integrity of heat-affected zones	(i)	HLW & reactor waste
	*Evaluation of quality control methods	-Development of processes during manufacturing and establishment of quality control methods -Development of non-destructive inspection techniques	(i)	HLW & reactor waste
	*Clarification of the photocatalyst mechanism	-Clarification and modeling of mineralization mechanisms of organic carbon using a photocatalyst	(i)	reactor waste
Low-pH cement	*Acquisition of data on low-pH cement and construction of models	-Development and validation of alteration models of low-pH cement -Development of nuclide migration parameters including state of alteration	(i)	HLW
	*Development of hydraulic characteristics of low-pH cement	-Understanding and modeling of percolation behaviour associated with alteration	(i)	HLW

* Included in planned laboratory experiments in ENTRY, QUALITY and external facilities

(**) Included in the research and development plan in domestic and international underground research laboratories

(i): Should be implemented in next five years

(ii): Should be implemented in accordance with a stepwise approach in projects

Table 8.3-5 Development of implementation technologies (detailed design methods)

Item	Issue	Content	Time	Overlap
Design of tunnels	(**)Establishing a method for evaluating the mechanical stability of an underground tunnel with a large cross-section	-Comparative analysis of the measured results of the behaviour of the surrounding rock (rock displacement, support stress, etc.) during excavation of an underground tunnel with a large cross-section and validation of applicability and validity of stability evaluation methods	(ii)	
	-Establishing a method for evaluating the mechanical stability of a tunnel against earthquake motion	-Establishment of a method for evaluating the mechanical stability of a tunnel against earthquake motion during construction and operation -Setting of input earthquake motion parameters, selection of components to be evaluated, classification of each component in order of importance and construction of models	(ii)	HLW
Design of engineered barriers	-Detailed design of each engineered barrier	-Optimization and specification of each engineered barrier, taking into account the geological environment, etc. of the site (foreseen for waste package, filling material, buffer material, structural framework, etc.)	(ii)	
	-Optimization of barrier systems for each waste type	-Optimization of composition/specifications of barriers in accordance with waste volumes and characteristics	(ii)	
Design of operating system	-Establishment of operating system	-Establishment of a rational repository operating system, taking into account characteristics of each waste type and operations in surface and underground facilities -Establishment of a physical material distribution system, a ventilation/exhaust system and ensuring flexibility with respect to changes in various conditions (volume of waste, schedule, etc.) -Establishment and verification of a comprehensive and rational operating system	(ii)	

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Table 8.3-6 Development of implementation technologies (construction technologies, etc.)

Item	Issue	Content	Time	Overlap
Construction / operation / closure technology	(**)Upgrading tunnel excavation technology	-Limiting formation of zones affected by excavation of disposal tunnels with large cross-sections; upgrading tunnel excavation technology and reducing construction times	(ii)	HLW
	*(**)Establishing technology for constructing buffer materials	-Establishment of optimum construction technology for buffer materials, taking into account underground environments, spatial constraints, waste characteristics, etc.	(ii)	
	*(**)Establishing waste emplacement technologies	-Establishment of transportation technology for moving waste between access tunnels and disposal tunnels and waste emplacement technology in disposal tunnels, taking into account characteristics of each waste form and waste package type -Establishment of filling technology using cementitious materials, etc. after emplacement of wastes	(ii)	
	*(**)Establishment of construction technology for structural framework	-Establishment of construction technology, taking into account spatial constraints and time schedules	(ii)	
	*(**)Establishment of construction technology for backfill materials	-Establishment of construction technology for backfill materials, taking into account spatial constraints on materials used (bentonite, cementitious materials) and construction parts -Evaluation of optimisation measures.	(ii)	HLW
	*(**)Establishment of construction technology for plugs	-Establishment of construction technology for installation of hydraulic plugs and mechanical plugs made from bentonite and cementitious materials	(ii)	HLW
	(**)Establishment of grouting technology	-Development of grouting technology using bentonite materials with the aim of maintaining watertight properties over the long term	(ii)	HLW
Security technology	(**)Establishment of maintenance methods for tunnels	-Establishment of maintenance methods/technologies for tunnels with large cross-sections	(ii)	
	*(**)Establishment of quality control methods for engineered barriers	-Establishment of quality control methods/technologies during construction of each engineered barrier and during the period up to closure of the repository	(ii)	
	*(**)Establishment of operational safety technologies	-Development of technologies for preventing accidents during operations in surface and underground facilities and designing controlled zones for handling radioactive wastes -Establishment of remote controlled techniques for recovery work in case of an accident	(ii)	
	*(**)Development of monitoring techniques	-Development of monitoring techniques during construction/operation/closure and post-closure repository phases (measurement techniques, wireless technology, etc.)	(ii)	HLW
	*(**)Development of retrieval techniques	-Evaluation of retrieval techniques for waste -Development of techniques for evaluating the status of waste in accordance with the operation phase (emplacement, post-emplacement, post-closure)	(ii)	

* Included in planned laboratory experiments in ENTRY, QUALITY and external facilities

(**) Included in the research and development plan in domestic and international underground research laboratories

(i): Should be implemented in next five years

(ii): Should be implemented in accordance with a stepwise approach in projects

References

TRU Coordination Team (2000): Outline of TRU waste disposal, Federation of Electric Power Companies, JNC TY1400 2000-001, TRU TR-2000-01. [written in Japanese]