OPERA FEP-database (OFD)

OPERA-PU-TNO2123A

Radioactive substances and ionizing radiation are used in medicine, industry, agriculture, research, education and electricity production. This generates radioactive waste. In the Netherlands, this waste is collected, treated and stored by COVRA (Centrale Organisatie Voor Radioactief Afval). After interim storage for a period of at least 100 years radioactive waste is intended for disposal. There is a world-wide scientific and technical consensus that geological disposal represents the safest long-term option for radioactive waste.

Geological disposal is emplacement of radioactive waste in deep underground formations. The goal of geological disposal is long-term isolation of radioactive waste from our living environment in order to avoid exposure of future generations to ionising radiation from the waste. OPERA (OnderzoeksProgramma Eindberging Radioactief Afval) is the Dutch research programme on geological disposal of radioactive waste.

Within OPERA, researchers of different organisations in different areas of expertise will cooperate on the initial, conditional Safety Cases for the host rocks Boom Clay and Zechstein rock salt. As the radioactive waste disposal process in the Netherlands is at an early, conceptual phase and the previous research programme has ended more than a decade ago, in OPERA a first preliminary or initial safety case will be developed to structure the research necessary for the eventual development of a repository in the Netherlands. The safety case is conditional since only the long-term safety of a generic repository will be assessed. OPERA is financed by the Dutch Ministry of Economic Affairs and the public limited liability company Electriciteits-Produktiemaatschappij Zuid-Nederland (EPZ) and coordinated by COVRA. Further details on OPERA and its outcomes can be accessed at www.covra.nl.

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Summary

This report describes the database of *features*, *events* and *processes* (FEPs) that has been established in the OPERA programme. The database plays an important role in safeguarding the quality of the *safety assessment*: firstly it is used as a tool for the identification of a comprehensive set of scenarios, and subsequently will be used for tracking the analyses of safety relevant factors in the performance assessment workflow.

The database is composed of a comprehensive and neutral basic set of FEPs. In addition it contains the results of a first screening sweep performed in OPERA, tailoring it to the specific needs of the Dutch programme. For each FEP, the relevance with respect to the safety of the Dutch disposal concept has been assessed, and FEPs have been assigned roles in one or more scenarios or *what-if* cases accordingly.

The FEP database will be used in relating detailed analyses based on the system description (*assessment basis*) and the *performance assessment* (PA) models developed for the *safety assessment* in OPERA.

Samenvatting

Dit rapport beschrijft de database van *features*, *events* en *processes* (FEPs), die binnen het OPERA programma is vastgesteld. De database heeft een belangrijke rol in de waarborging van de kwaliteit van de *safety assessment*: ten eerste bij het samenstellen van een volledige set relevante scenario's, en vervolgens bij het volgen van de analyses van de veiligheidsrelevante factoren gedurende de veiligheidsanalyse.

De database bestaat uit een basisset FEPs die zo volledig en neutraal mogelijk is, en de resultaten van de eerste screening binnen OPERA, die hem specifiek voor het Nederlandse programma maken. FEPs zijn daarbij beoordeeld op hun relevantie voor de veiligheid van het Nederlandse opbergconcept en hebben een rol toegekend gekregen in een of meerdere scenario's of *what-if* assessment cases.

De FEP database zal gebruikt worden om de analyses van de op basis van de systeembeschrijving (*assessment basis*) ontwikkelde detailmodellen te vertalen naar *performance assessment* (PA) modellen ten behoeve van de *safety assessment* in OPERA.

1. Introduction

1.1. Background

In 2011 COVRA defined a five-year research programme for the geological disposal of radioactive waste, OPERA, entitled "OnderzoeksProgramma Eindberging Radioactief Afval". The main aim of the OPERA programme is to develop an initial, conditional Safety Case for geological disposal within the Dutch context. The focus of the research programme is on radioactive waste disposal in the Boom Clay, which is present in the deep subsurface of the Netherlands.

The OPERA research program [Verhoef, 2011b] broadly covers all aspects of the OPERA Safety Case, in particular the assessment basis/system description and the safety assessment. Work Package 2 of the OPERA research program provides the tools needed for integrating the research results into the OPERA Safety Case. One of these tools is the OPERA FEP Database (OFD), which has been developed in WP 2.1.2.

1.2. Objectives

The OPERA FEP database is produced for the purpose of the safety assessment, which is performed in OPERA WP7. In order to handle the variability, (un)predictability and uncertainties concerned with the large timescales considered in OPERA, *scenarios* are defined in the safety assessment: descriptions of possible future evolutions of the disposal system. The use of FEPs is an internationally acknowledged tool for developing and evaluating a comprehensive set of scenarios and their descriptions [e.g. NEA, 2012; p.10].

Besides its function as a tool in scenario formation, the OPERA FEP database also fulfills a role in recording the scenario formation process and subsequently the analyses of the scenarios in assessment models. In order to control the quality of the safety assessment's conclusions, the argumentation and analyses underlying the conclusions are captured in the database. As the Dutch disposal program is still in an early phase, investigations will become more in depth in due course. This fact only strengthens the need for good bookkeeping with respect to decisions made in the assessment, as early results will influence choices made in later research stages.

1.3. Realization

The OPERA FEP Database (OFD) has been prepared by the OSCAR consortium, comprised of NRG, TNO, GRS and EnviroLogic. The OFD is the result of a two-staged approach: first, a comprehensive basis has been defined, in line with recent international practice [NEA, 2012; p.10]. This resulted in the basic version of the OFD database, released project internally in 2013. This basic version of the OFD has been used in a FEP screening process in WP7 [Grupa, 2013]. In that process, OPERA WP7 experts have assessed all FEPs in the OFD and considered their relevance for OPERA. The outcomes of this process have been recorded in the OFD, and form, together with the basic OFD version described before, the present OFD.

In the OPERA research Plan [Verhoef, 2011b; p.8] the OFD is referred to as Deliverable M2.1.2.3. For practical reasons, this deliverable consists of two parts:

- OPERA-PU-TNO2123A: the present report describing the OFD
- OPERA-PU-TNO2123B: the spreadsheets containing the OFD

1.4. *Contents of this report*

Chapter 2 describes the basis of the OFD. Chapter 3 contains a summary of the screening procedure performed on this basis as well as the resulting changes to the database. Chapter 4 contains the concluding remarks.

2. OPERA FEP database basis

For the OPERA Safety Assessment, a set of scenarios has been developed in order to quantitatively analyse the performance of the disposal system. Scenario outlines for a disposal in clay have already been developed since the earliest safety assessments for geological disposal. For example, in the EC PAGIS study of 1988 [Stork, 1988], Normal Evolution Scenarios and two Altered Evolution Scenarios (climatic changes and faulting) were identified for two reference sites, one in the Boom clay and one in the Oxford clay. Since then in the various national and international programmes the list of scenarios has grown considerably. Achieving completeness, comprehensiveness and sufficiency in the selected set of scenarios used in the safety assessment are the key initial concerns.

Various graphical and tabular techniques have been used to assist in scenario development, its communication and documentation [NEA, 2001, p.15]. The developed scenarios establish the basis for model development, starting off with the Normal Evolution Scenario and the most critical Alternative Scenarios. Whatever techniques are used, the model derivation process relies on the judgment of PA modellers and scientific subject experts, trying to ensure that the scientific understanding is appropriately incorporated in the models. A key value of the graphical and tabular techniques is to aid communication within projects, enabling experts to see the significance of their knowledge within the system context, and to discuss its incorporation. The techniques can also provide a logic for comprehensive documentation of the relevant processes and their treatment in models [NEA 2001, p.16].

The main objectives of FEP analysis for scenario development are generally agreed to be the following [NEA 2001, p.14]:

- To demonstrate or try to ensure completeness, comprehensiveness and sufficiency in the scope of a PA, usually by seeking to identify, and possibly describe, a list of relevant features, events and processes (FEPs).
- To decide which FEPs to include in PA and how to treat them. This includes screening of less important FEPs, deciding which FEPs are to be treated in quantitative models of system performance, which FEPs can be handled by scoping calculations and which FEPs should be regarded as the key defining elements of separate scenarios.
- To demonstrate traceability from data and information to assessment scenarios, models and calculation cases.

Since the OPERA outline of a disposal concept in clay [Verhoef, 2011] is a largely generic design it is not possible to identify site-specific FEPs, so the use of publicly available FEP descriptions is expected to be adequate.

Nevertheless, an important prerequisite of the OPERA FEP database (OFD) is that it should be in agreement with international, and more specifically Belgian, practice. As is stated explicitly in the OPERA research plan, close cooperation between the Belgian and Dutch programs is advisable, and existing knowledge from the Belgian research program should be used where possible. Furthermore, the OFD should be in line with the overall OPERA focus, which is long-term safety of geologic disposal of radioactive waste.

The OFD has therefore been composed of two existing FEP lists:

- a general list from the Nuclear Energy Agency [NEA, 2000; see Section 2.1] and
- a concept-specific list from the Belgian Waste Management Organisation ONDRAF/NIRAS (see Section 2.2).

Both lists have been described within the preliminary results of NEA's project of updating the international FEP database that has been in use since 2000 (Little, 2012 (task 1 and task 2)). Though not yet published in its final form, it is expected that changes with respect to these documents will be minor. The database is anticipated to become available in 2015. In our opinion, the benefit of using the most recent but not yet published, comprehensive, internationally supported and detailed FEP database available as the general basis for the OPERA assessment is greater than using the less comprehensive (outdated) but published version of the NEA FEP database.

For more information on the FEPs specifically related to the Boom Clay, one of the potential Dutch host rocks, we advise to use the clay-focused FEPCAT (Mazurek, 2003). The FEPs listed in that work are already included in the present OPERA database via the NEA part; FEPCAT has added value because of its supplementary information. Besides definitions, FEPCAT provides for each FEP experimental data, discussion on up- and downscaling issues and (scientific) understanding, connections with other FEPs and site-specific references, leading to a deeper understanding of the FEPs relevant for argillaceous host rocks. It is emphasized that FEPCAT should not be used as an extension of the database itself, but rather as a source of relevant background information.

2.1. NEA's updating project

In 2010, NEA sent a questionnaire on the use of FEPs in national programs to the members of its Integration Group for the Safety Case (IGSC). Based on the outcomes of the questionnaire, it was decided to revise the existing NEA International FEP List dating from 2000, and provide an updated list and web-based database, using the developments in the national programs and focusing on post-closure safety of all designs of geological disposal facilities for all categories of radioactive waste. So far, two of four tasks have been completed:

- the relevant project-specific FEP lists provided by the IGSC members have been reviewed (Little, 2012 (task 1))
- the proposed revisions to the NEA International FEP List of 2000 have been identified, agreed and documented (Little, 2012 (task 2)).

The result of the next step, the implementation of the revised list in a prototype web-based database, is expected to be accomplished 2016.

Although quite a number of new FEPs were added, still many FEPs have been imported from [NEA, 2000], and FEP definitions remain unchanged for the majority of items. The revised list is structured differently than the former version, and a fourth level of detail has been added for part of the FEPs.

In the present OPERA FEP database, the definitions and comments from (NEA, 2000) have been used where available, supplemented by relevant comments from (Little, 2012 (task 2)). The list consists of five FEP categories:

1. External Factors
2. Waste Package Factors
3. Repository Factors
4. Geosphere Factors
5. Biosphere Factors.

The FEPs in these categories have been listed in separate worksheets in the database.

2.2. ONDRAF/NIRAS Supercontainer EBS FEP List

The OPERA FEP database has been supplemented by a FEP list concerning a specific engineering feature of the OPERA disposal concept, the so-called Supercontainer. The Supercontainer is a cement-based engineering design developed by ONDRAF/NIRAS and is also applied in the OPERA disposal concept (Verhoef, 2011; Section 5.4). The cement-based Supercontainer is part of the Engineered Barrier System (EBS), which makes the ONDRAF/NIRAS list also relevant for the OPERA programme.

Next to the EBS FEP list, ONDRAF/NIRAS developed a list of natural events and processes. Because the latter list has already been covered by the NEA list, it is not further considered here.

The Supercontainer EBS FEP list focuses on the specific Belgian proposed disposal system. It is not intended to be complete, but rather highlights research areas which need further attention. The list is structured into six FEP categories:

- D – Disposal System,
- R – Radiological Processes,
- C – Chemical Processes,
- H – Hydraulic Processes,
- T – Thermal Processes and
- P – Physical / Mechanical Processes.

For the OPERA database, the EBS FEP list as it is presented in Appendix C of (Little, 2012 (task1)) has been used including the FEP descriptions and FEP effects. It must be noted that presently ONDRAF/NIRAS is updating the Supercontainer EBS list, the results of which will be included in a future NIROND report. When using the OPERA database in the future, it would be best to update the current Supercontainer EBS list with the new information when it is available.

It was decided to maintain the numbering used in the NEA IFEP database and the Supercontainer EBS FEP list. The OPERA FEP list therefore consists of eleven FEP categories:

NEA 1. External Factors
NEA 2. Waste Package Factors
NEA 3. Repository Factors
NEA 4. Geosphere Factors
NEA 5. Biosphere Factors
EBS -D – Disposal System
EBS -R – Radiological Processes
EBS -C – Chemical Processes
EBS -H – Hydraulic Processes
EBS -T – Thermal Processes and
EBS -P – Physical / Mechanical Processes.

For reference, the original lists have been added as separate worksheets.

3. OPERA screening results

3.1. FEP screening process

The OFD not only incorporates the FEP lists, but has also been extended with records of the experts' decisions on the role of a FEP in the scenarios. A summary of the screening procedure is presented below. The scenarios and the screening process has been elaborated in [Grupa, 2013].

Starting point of the screening process are the safety functions underlying the safety of the disposal concept (Smith, 2009; p.25):

- engineered containment (C),
- delay and attenuation of the releases (R), consisting of
  - R1: limitation of contaminant releases from the waste forms,
  - R2: limitation of the water flow through the disposal system, and
  - R3: retardation of contaminant migration, and
- isolation (I), consisting of
  - I1: reduction of the likelihood of inadvertent human intrusion, and
  - I2: ensuring stable conditions for the disposed waste and the system components.

Two NRG experts and one expert from TNO answered for each FEP in the spreadsheets the question *“Is it conceivable that a cause-effect chain exists, in which this FEP leads, either directly or indirectly, to damage to one or more safety functions of the Dutch disposal system?”* Part of the biosphere factors have not been included in the screening, as no safety functions are allocated to the biosphere.
If the answer to the above question turned out to be positive, the “FEP role” for this FEP was set to “Safety Function Hazard” (see Figure 3-1) and the expert indicated which safety functions could be affected and in which scenario and assessment case or what-if case this cause-effect chain is analyzed (see Figure 3-2).
If the answer turned out to be negative, there were two possibilities:

- Option 1: the FEP can be considered to be irrelevant for the Dutch boundary conditions, or no process can be identified in which the FEP significantly affects any of the safety functions. Where this judgment was given, argumentation by the expert has been provided under “Remarks” and the FEP role has been set to “Irrelevant” (see Figure 3-3).
- Option 2: the FEP is relevant for completing the description of the system in the scenario assessments, but does not by itself define a scenario, assessment case or what-if case). The FEP role has then been set to “System description”. In some cases, the considered FEP *does* define an assessment case or what-if case, and at the same time is part of the description of the system in other cases. Those FEPs have been assigned two FEP roles accordingly.

Note that, because no safety function has been defined in the biosphere domain, no *safety function hazard* FEPs can be identified in this FEP category.

Experts also had the possibility to add FEPs or to extend already included FEPs by adding an extra level of detail. In those cases, the names of the new FEPs are shown in brown and indicated in the spreadsheet as OPERA-specific.

Experts provided extra information in the *Remarks* column. Initials of the judging experts and the date have been added to enhance traceability of the argumentation.

FEP Title (*original NEA IFEP no)* level 3	FEP Number level 4	FEP Title (*original NEA IFEP no)* level 4	FEP role	
Thermal processes (waste package) (2.1.11)	2.3.01.01	Radiogenic heat production and transfer	Safety function hazard	Scenario description
	2.3.01.02	Chemical heat production and transfer	*Irrelevant*	
	2.3.01.03	Biological heat production and transfer	*Irrelevant*	
	2.3.01.04	Impact of thermal processes on other processes (waste package)	Scenario description	
Hydraulic processes (waste package) (2.1.08)	2.3.02.01	Resaturation/desaturation (waste package)	Scenario description	
	2.3.02.02	Thermal effects (waste package)	Scenario description	
	2.3.02.03	Gas effects (waste package)	Safety function hazard	
	2.3.02.04	Impact of hydraulic processes on other processes (waste package)	Scenario description	

Figure 3-1 OFD detail concerning the recording of the expert judgment on the FEP role

FEP role		affected safety function						part of scenario – assessment case
			Delay and attenuation of releases R			Isolation I		
		Engineered containment C	Limitation of containment releases from the waste forms R1	Limitation of water flow through the system R2	Retardation and spreading in time of contaminant migration R3	Reduction of the likelihood of inadvertent human intrusion and of its possible consequences I1	Ensuring stable conditions for the disposed waste and the system components I2	
Safety function hazard		X	X	X				N3 Gas pressure buildup case (normal range) EGC1 Excessive Gas assessment case
Scenario description								
Scenario description								
Irrelevant								
Scenario description								
Safety function hazard		X		X				EGC1 Excessive Gas assessment case
Safety function hazard		X		X				EGC1 Excessive Gas assessment case

Figure 3-2 OFD detail concerning the recording of the expert judgment on the potential impact on the safety function and the attribution to assessment cases

FEP role		affected safety function						part of scenario - assessment case	remarks
			Delay and attenuation of releases R			Isolation I			
		Engineered containment C	Limitation of containment releases from the waste forms R1	Limitation of water flow through the system R2	Retardation and spreading in time of contaminant migration R3	Reduction of the likelihood of inadvertent human intrusion and of its possible consequences I1	Ensuring stable conditions for the disposed waste and the system components I2		
Irrelevant									No active volcanic and magmatic activity foreseen in the Netherlands
Irrelevant									Not relevant for the type of host rock and the relativley low p and T at the depth of the host rock
Irrelevant									Geothermal gradient is too low to trigger hydrothermal activity
Irrelevant									The larger part of the Netherlands is subject to subsidence wihich limits the amount of regional erosion.

Figure 3-3 OFD detail concerning the recording of the expert remarks with respect to the judgment

3.2. *Database screening results*

The procedure described above results in the identification of 79 *safety function hazard* FEPs. 70 FEPs are considered irrelevant at this moment, and 191 FEPs (excluding part of the biosphere FEPs) will be part of the scenario descriptions in the safety assessment without being considered a threat to the safety functions (see table 3-1; note that some FEPs have been double-counted because of multiple roles). Seventeen FEPs have been added to the database, all as level four elaborations of already included level three FEPs, and all in subcategory *Geological factors* of NEA FEP category *External factors*. Table 3-2 lists the additional FEPs. Biosphere FEPs will be elaborated in OPERA Task 6.3.1 on biosphere modelling.

For almost all FEPs, the experts have provided extra information concerning their judgment in the Remarks column.

Table 3-1 Numbers of attributed FEP roles by FEP category

FEP category	Number of *safety function hazard* FEPs	Number of *scenario description* FEPs	Number of *irrelevant* FEPs
NEA - External factors	25	23	20
NEA - Waste package factors	13	60	12
NEA - Repository factors	8	33	18
NEA - Geosphere factors	7	27	11
NEA - Biosphere factors	0	not yet determined	not yet determined
EBS - Disposal system D	7	9	0
EBS - Radiological processes R	1	4	0
EBS - Chemical processes C	7	17	1
EBS - Hydraulic processes H	3	10	5
EBS - Thermal processes T	1	3	2
EBS - Physical /Mechanical processes P	7	5	1

Table 3-2 FEPs added to the database

FEP Number level 3	FEP Title (original NEA IFEP no) level 3	FEP Number level 4 - OPERA-specific	FEP Title level 4 - OPERA-specific
1.2.01	Tectonic movement (*1.2.01*)	1.2.01.01	Regional uplift
		1.2.01.02	Regional subsidence
		1.2.01.03	Movement along faults
		1.2.01.04	Glaciotectonic movement
		1.2.01.05	Diapiric movement
1.2.02	Orogeny (*1.2.01*)		
1.2.03	Deformation (elastic, plastic or brittle) (*1.2.02*)	1.2.03.01	Deformation by intraplate fault movement
		1.2.03.02	Deformation by glacial loading
		1.2.03.03	Deformation by permafrost formation
		1.2.03.04	Deformation by compaction
1.2.04	Seismicity (*1.2.03*)	1.2.04.01	Intraplate seismic movement
		1.2.04.02	Glaciotectonic seismicity
1.2.05	Volcanic and magmatic activity (*1.2.04*)		
1.2.06	Metamorphism (*1.2.05*)		
1.2.07	Hydrothermal activity (*1.2.06*)		
1.2.08	Regional erosion and sedimentation (*1.2.07*)	1.2.08.01	Regional erosion
		1.2.08.02	Regional sedimentation
		1.2.08.03	Glaciation induced
1.2.09	Diagenesis (*1.2.08*)		
1.2.10	Pedogenesis		

FEP Number level 3	FEP Title (original NEA IFEP no) level 3	FEP Number level 4 - OPERA-specific	FEP Title level 4 - OPERA-specific
1.2.11	Salt diapirism and dissolution (*1.2.09*)		
1.2.12	Hydrological/Hydrogeological response to geological changes (*1.2.10*)	1.2.12.01	Flooding
		1.2.12.02	Change in groundwater level
		1.2.12.03	Fresh/salt water intrusion

4. Conclusion

The present report and accompanying database updates and enhances existing FEP lists for the disposal of radioactive waste in Boom Clay, and provides a framework for recording the expert judgment FEP screening in the scenario development process that is part of the safety assessment. The OPERA FEP Database (OFD) has been set up to comply with the NEA IFEP database that covers the whole disposal system on a generic level as well as the specific ONDRAF/NIRAS Supercontainer EBS FEP List, expanded with records describing the expert judgments.

Besides the application of the database in establishing the set of scenarios to be analysed in OPERA WP7 and recording the procedure behind it, other uses of the database are anticipated. In OPERA Task 7.1.2, the FEPs underlying the scenarios are decomposed into the governing THMCB mechanisms in order to structure the translation of scenarios into model concepts with input from OPERA THMCB experts. FEPs are converted from qualitative descriptions to mathematical formulations that feed into the computer models. The database is used in this process to provide insight in the FEPs connected to the various scenarios and to organize the acquired information.

Inclusion of the FEP translations and their connections to the various models, enables traceability in later stages of the OPERA programme and beyond. Relevant FEPs, especially those that have been identified as safety function hazards, should of course be analysed adequately.

After OPERA, the Dutch disposal concept will likely be subject to more elaborate investigations. Later research should be able to build on previous work. This is only possible if choices and argumentation are well recorded for future reference. The first screening process has been tackled; we advise to use the present OFD as a living document, adding any future expert judgments.

A large number of FEPs have been identified as being relevant for the safety assessment. Indeed, in this early phase of the Dutch programme, it seems to be safest to discard only those FEPs that can be excluded *a priori*. However, the large numbers may compromise the transparency of the database when tracking the FEP analyses in later stages of OPERA. Future application will show if the intended use is feasible for all FEPs at this moment.

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