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- Preliminary Data Quality Evaluation for Boreholes HDB-1 to 8 -

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Groundwater/Porewater Hydrochemistry at Horonobe URL: Data Freeze II - Preliminary Data Quality Evaluation for Boreholes HDB-1 to 8 -

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Work has been currently ongoing to establish an appropriate quality management system (QMS), which is applicable to all aspects of the site characterisation process, through studying the host sedimentary formations at the site of the Horonobe Underground Research Laboratory in northern Hokkaido, Japan. A quality assurance (QA) audit of hydrochemical datasets for JAEA's deep boreholes HDB-9–11 was carried out by applying both the groundwater QA methodology employed in the recent site assessments in Sweden and a porewater QA regime newly proposed in this study. Both methodologies assign QA categories to the data, indicating the quality 'levels' of the data for anyone who will use the data in the future, whether it be for hydrochemical modelling or a repository safety assessment.

For the remaining deep boreholes HDB-1–8, a QA audit of hydrochemical datasets has recently been carried out along similar lines to that of the previous study. The HDB-1–8 hydrochemical data were generally classified into low QA categories, as was the case for boreholes HDB-9–11, due mainly to a lack of relevant information, such as the records of groundwater sampling and analytical methodology, which could be used to more fully assess the data quality. As such, a formalised field manual for hydrochemical sampling has been developed, following the assessment of potential processes that could influence the quality of hydrochemical data. This preliminary system has been tested in the field by a group of experts and amended to take into account their technical feedback.

This report presents the results of the second QA audit (of the HDB-1–8 data) and the formalised field manual (Release candidate 1) as well as the progress of work to further improve the site characterisation QMS.

Keywords: Horonobe URL Project, Groundwater, Porewater, Quality Assurance, Category, Field Manual

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幌延深地層研究計画における地下水・間隙水の地球化学的特性調査
－HDB-1～8 孔の地球化学データセットの品質評価－

日本原子力研究開発機構　地層処分研究開発部門

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幌延深地層研究計画では，北海道幌延町に分布する堆積岩を事例とした調査・評価を通じて，候補サイトの地質環境特性を体系的に調査・評価する際に不可欠なツールの一つである品質マネジメントシステムの整備を進めている。これまでに，ボーリング調査（HDB-9～11 孔）で取得した間隙水と地下水の地球化学データセットを対象に，スウェーデンのサイト特性調査において適用された地下水水質の品質保証の手法に加え，新たに提案した間隙水水質の品質保証の指針を適用して品質保証区分を実施した。この区分によって示されるデータの品質は，地下水の地球化学モデリングや性能評価といった目的に応じてデータを用いる際の指標となる。

以上の結果を踏まえ，HDB-1～8 孔で取得した間隙水と地下水の地球化学データセットについて品質保証区分を行った結果，HDB-9～11 孔と同様に，9 割以上のデータが低品質のカテゴリーに分類された。この主な理由として，品質保証区分に必要な情報（例えば，採水作業や試料の分析方法などに関する記録）が残されていないことが挙げられたことから，間隙水と地下水の地球化学データの取得における一連の作業の品質管理を目的として，既存の調査で個別に整備した調査手順書やマニュアルなどを整理し，「採水調査における現場品質マニュアル（第 1 版）」を整備した。

本報告書では，以上の結果を示すとともに，サイト特性調査に必要な品質保証区分における評価基準の明確化に向けた取り組みについても述べる。

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Contents

目　次

1. Introduction

The Horonobe Underground Research Laboratory (URL) Project is a comprehensive research and development (R&D) project aimed at studying the sedimentary formations in the area of Horonobe Town in Hokkaido, northern Japan. The Horonobe URL is one of two in Japan (the other is at Mizunami in central Japan – see Figures 1.1) which are run by the Japan Atomic Energy Agency (JAEA) as part of the national generic R&D programme for the geological disposal of high-level radioactive waste[1)].

In Horonobe, work is currently ongoing to characterise the site of the URL and, through this, improve the tools currently used for the hydrogeological and hydrochemical characterisation of repository site host rocks. Surface-based investigations are largely completed[2)] and one of the remaining issues is the development of an appropriate quality management system (QMS) which is applicable to all aspects of the site characterisation process.

This report covers two areas which are currently being tackled within the Horonobe QMS:

- an ongoing assessment of the quality of the existing groundwater and porewater datasets;
- the development of a field manual which aims to lay down guidelines for on-site groundwater and rock matrix sampling procedures.

In the case of the former task, existing work on the site hydrochemistry (including a preliminary evaluation of the hydrochemical datasets from boreholes HDB-9–11) is reviewed[3)]. Here, a preliminary evaluation of the hydrochemical datasets from boreholes HDB-1–8 is made along similar lines to that of the previous study. As the porewater data are probably a more significant part of the site characterisation toolkit than the groundwaters (as there are currently many more porewater data than groundwater data), it was decided that a similar QMS should be applied to both groundwater and porewater sample and data sets and this novel process will be examined in more depth here.

For the latter task, it was recognised that the development of a formalised field manual would be very useful in ensuring that samples are collected in a state-of-the-art manner. This would not only save wasted effort by avoiding the need to re-sample and re-analyse material, it would also ensure that operator error is removed. This is important in the Horonobe URL project as not only JAEA are involved in groundwater and porewater sampling, but it will also be extremely important in any future repository site characterisation in Japan when several boreholes may be developed in parallel and where groundwater sampling will continue over several years.

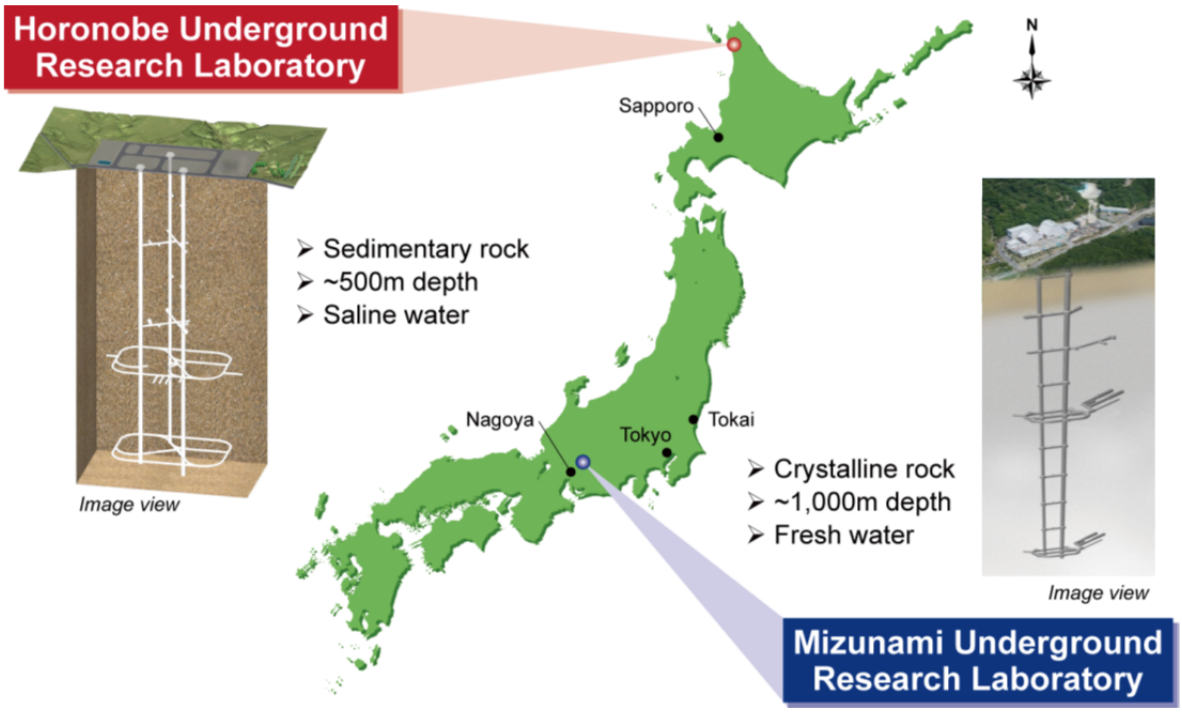

Figure 1.1: Location of both JAEA URLs in Japan[2)]

2. Groundwater and porewater data quality assurance

2.1 The need for a QMS in site characterisation

Although a repository site characterisation is essentially an application of geoscientific tools and models, it cannot be forgotten that the future repository will be a nuclear installation and, as such, standard nuclear industry levels of QMS must be applied. As noted in IAEA[4]:

"The quality assurance programme is a part of the overall quality assurance programme for the nuclear installation. However, since activities for site investigation are normally initiated long before the establishment of a nuclear project, the quality assurance programme should be established at the earliest possible time consistent with its application in the conduct of site evaluation activities for the nuclear installation... A quality assurance programme shall be implemented for all activities that may influence safety or the derivation of parameters for the design basis for the site."

Arguably, the quality assurance (QA) methodologies applied in radioactive waste disposal programmes are much more stringent than in other areas of hydrochemical study because of the strict requirements of repository site assessments as noted above. In addition to this clear technical (and, in some national programmes, legal) requirement to ensure quality in the site characterisation programme, a move towards more active involvement of the general public in establishing waste management programmes means that a more transparent approach is necessary[5] and this can only really be attained with a functional QMS in place. As noted in Alexander et al.[6]:

"The HLW repository projects with most local acceptance – in Finland and Sweden – have coupled the technical aspects of site selection with intensive dialogue with local communities."

That both programmes also have a well-developed site characterisation QMS in place is no coincidence.

Although the Horonobe URL will not be used as a repository, the high quality practices and standards developed as part of the URL project can be used to set standards elsewhere in the Japanese national programme (and other international programmes). This will obviously have clear advantages when developing an integrated conceptual model for the URL site as high quality data are required to model the hydrogeochemical interactions in the groundwater and host rock – a functional QMS will increase confidence in the data and the so-produced site models. In addition, training staff in the application of appropriate QMS methods at such a generic URL site will allow the development of a body of staff fully capable of conducting an actual repository site characterisation.

The procedures employed in the QA of the Horonobe hydrochemical datasets are laid out in detail[3), 7), 8)] and so will only be briefly reviewed here. Basically, many processes can influence

groundwater and porewater chemistry (see Chapter 3 for details) and so it is necessary to evaluate them and to assign a value to the data which reflects the data quality. As mentioned above, the QA methodologies applied in radioactive waste disposal programmes are much more stringent than in other areas of hydrochemical study because of the strict requirements of repository site assessments and the expectations of various stakeholders[5]. Here, the QA classification system follows that of Laaksoharju et al.[9] and Smellie and Tullborg[10] for groundwaters (Table 2.1) and as modified by Kunimaru et al.[3] for porewaters (Table 2.2). Although this QA categorisation is used throughout this report, it should be noted that ongoing development of the system means that the QA categorisation assigned here may well change in the future.

Categories 1–3 primarily meet the requirements of hydrochemical (but also hydrogeological) modelling, while Categories 4–5 primarily meet hydrogeological requirements (but may also be of use for more qualitative hydrochemical modelling with caution). Smellie and Tullborg[10] defined a colour code to make sample identification easier when, for example, data are presented in spread-sheet tables or as symbols in scatter plots:

- Category 1 is orange;
- Category 2 is yellow;
- Category 3 is green;
- Category 4 is grey;
- Category 5 is black.

As can be seen from Table 2.1, the final weighting of data for any particular groundwater sample is based on providing:

- period of sample collection (e.g. during drilling or hydraulic testing lowers the category);
- a complete set of major ion and isotope analytical data (particularly H, O and C isotopes when available);
- an acceptable charge balance;
- a low drilling water content;
- good time-series data coverage*;
- reliable redox values;
- a satisfactory coverage of trace element data (including U, Th and REEs);
- dissolved gas, microbes and organics and colloid data.

For the porewater data (Table 2.2), it is clear that the same set of QA conditions cannot be applied, but some QA aspects can be addressed, such as the degree of drilling fluid penetration into the core to be used for porewater extraction[11], the data set available and

*In Table 2.1, it is stated as 'adequate' and 'inadequate', without any comment on just how adequate this must be and this, unfortunately, can lead to confusion. This will be addressed in Data Freeze III.

indications of perturbations such as sample oxidation or CO_2 reaction (depending on the rock type, groundwater type etc). Of particular note is the addition of analytical data quality, including the requirement to properly assess and report analytical uncertainty. Unfortunately, for these early Horonobe data, only an ad hoc QA system was in place and so a stringent assessment was not possible. This is currently changing and new QA measures (see Chapter 3, for example) are being introduced, which will enable more detailed assessments of future datasets.

Table 2.1: Classification criteria for groundwater from cored boreholes[10)]

Groundwater	Category				
Aspects/Conditions	1	2	3	4	5
Drilling water (≤1%)	X	X	X	X	X
Drilling water (≤5%)		X	X	X	X
Drilling water (≤10%)			X	X	X
Drilling water (>10%)				X	X
Time series (adequate)	X	X	X	X	X
Time series (inadequate)			X	X	X
Time series (absent)				X	X
Suitable section length	X	X	X	X	X
Sampling during drilling				X	X
Sampling during hydraulic testing			X	X	X
Tube sampling					X
Charge balance ±5% (±10% for <50 mgL^{-1} Cl)	X	X	X	X	X
Major ions (complete)	X	X	X	X	X
Major ions (incomplete)			X	X	X
Environmental isotopes (complete)	X	X	X	X	X
Environmental isotopes (incomplete)		X	X	X	X
Hydraulic effects (short-circuiting)	X	X	X	X	X

Table 2.2: Preliminary classification criteria for squeezed porewater[3)]

Porewater	Category				
Aspects/conditions	1	2	3	4	5
Drilling water (≤10%)	X	X	X	X	X
Drilling water (≤50%)		X	X	X	X
Drilling water (>50%)				X	X
Oxidation/CO_2 reaction			X	X	X
Quality assured sampling methodology	X	X	X	X	X
Quality assured analytical data, including uncertainties	X	X	X	X	X
Chlorinity	X	X	X	X	X
δD	X	X	X	X	X
$\delta^{18}O$	X	X	X	X	X
^{3}H		X	X	X	X
Major elements			X	X	X
pH			X	X	X
Alkalinity			X	X	X
Immediately adjacent groundwater analysis available		X	X	X	X

2.2 QA of the hydrochemical data from boreholes HDB-1 – 8

The raw data are presented in Kunimaru et al.[12] and, for all boreholes, it is assumed that the drilling tracer is maintained at a concentration of 10±1 mgL^{-1} [2].

2.2.1 Borehole HDB-1

(1) Surface/shallow waters

The surface waters have a full set of analyses (apart from environmental isotopes) but only a short time series (some six months, so seasonal changes cannot be fully assessed) and so could be assigned to Category 3 (pending a charge balance check). The laboratory check on the field pH and electrical conductivity (EC) data indicates some worrying inconsistencies, however, with differences of up to 1.5 pH units and 2.1 mSm^{-1}. The EC generally increases, perhaps suggesting evaporation of the samples during transport and storage, whereas the pH shows signs of both CO_2 uptake and loss. As there is no way of being sure what has happened to these samples, they will be downgraded to Category 4.

(2) Deep groundwaters

Series 1-pu-1-1–5

The return water tracer concentration varies between 2.73 and 12.51 mgL^{-1}, i.e. well exceeding the stated uncertainty[12]. In addition, the pH of the return water fluctuates significantly, indicating clear downhole reactions (probably with cement, in some cases). It is of note that, apart from the first sample of the series, these samples appear to have low drilling fluid contents (1.4–3.0 mgL^{-1}) but, at the same time, the Cl^- content of the water climbs steadily with time, reaching around the same level as the neighbouring porewaters (sample 1-co-16-1) by the last sample. Unfortunately, no weight can be given to these data because of the above noted variations in the drilling fluid tracer. As such, these uncertainties imply that all are Category 4 (as Category 5 only refers to tube sampled waters). Only one sample, 1-pu-1-5, has an incomplete set of environmental isotope data, the rest have none. In addition, the time series is also inadequate (only seven days) and no sample timing has been noted.

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that some Cl^- and stable isotopic data are available and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. The porewater data are thus all Category 4. Incidentally, the value of the porewater data is also decreased by the fact that only two samples, 1-co-16-1 and 1-co-16-2, have adjacent groundwater data available (see also comment above).

2.2.2 Borehole HDB-2

(1) Surface/shallow waters

The surface waters have a full set of analyses (apart from environmental isotopes) but only a short time series (just over five months) and so could be assigned to Category 3 (pending a charge balance check). The laboratory check on the field pH data indicates some worrying inconsistencies with variations of up to 1.5 pH units noted. That the laboratory EC is always greater than in the field (with a maximum difference of 1.89 mSm^{-1}), once again suggests sample evaporation. Thus these data are Category 4.

(2) Deep groundwaters

Series 2-pu-1-1–2

The return water tracer concentration varies between 6.87 and 12.20 mgL^{-1}, i.e. well exceeding the stated uncertainty[12]. In addition, the pH of the return water fluctuates significantly, indicating clear downhole reactions (probably with cement, in some cases). In the end, this is irrelevant as no tracer check was carried out on the groundwater sample 2-pu-1-1. As such, this sample is Category 4 (as Category 5 only refers to tube sampled waters). The other samples, 2-pu-1-2, has an incomplete set of environmental isotope data and a full microbial sample set plus a drilling content of only 9%. There is some difference in the pH between the laboratory and the field and the field EC appears to be unusually low and may be a typographic error. Taking all aspects together, it is unfortunately not possible to rate this sample above Category 3. In addition, the time series is also inadequate (only seven days) and no sample timing has been noted.

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that Cl^- and stable isotopic data are available for most samples and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. The porewater data would thus all plot as Category 4. Four samples, 2-co-7, 2-co-8-1, 2-co-8-2 and 2-co-9, have adjacent groundwater data, even if the sample interval is somewhat large, and these will be useful for conceptual model development.

2.2.3 Borehole HDB-3

(1) Surface/shallow waters

The surface waters have a full set of analyses (apart from environmental isotopes) but only a short time series (just under five months) and so could be assigned to Category 3 (pending a charge balance check). There is no laboratory check on the field pH or EC data, therefore all data are Category 4.

(2) Deep groundwaters

Series 3-pu-1-1–4

The return water tracer concentration varies between 8.38 and 10.78 mgL^{-1}, i.e. slightly larger than the stated uncertainty and so the drilling water contents of 20–30% (in the last three of the four samples) are assumed to have some uncertainty[12]. Relatively stable pH values in these three samples are positive*, but there are still some differences between the field and laboratory EC values (N.B. the field value for sample 3-pu-1-1 looks unusually low). As such, 3-pu-1-1 to 3-pu-1-3 are Category 4 (as Category 5 only refers to tube sampled waters). Sample 3-pu-1-4 has an almost complete analysis, including a set of environmental isotope data and a full microbial analysis, so Category 3 could be assigned. However, drilling tracer content is >10%, so it must be assigned Category 4. In addition, the time series is also inadequate (not quite two days).

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that Cl^- and stable isotopic data are available for most samples and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. The porewater data would thus all plot as Category 4. None of the samples have adjacent groundwater data.

2.2.4 Borehole HDB-4

(1) Surface/shallow waters

The surface waters have a full set of analyses (apart from environmental isotopes) but only a short time series (just under five months) and so could be assigned to Category 3 (pending a charge balance check). There is no laboratory check on the field pH data.

(2) Deep groundwaters

Series 4-pu-1-1 to 4-pu-4-1

The return water tracer concentration varies between 8.19 and 10.67 mgL^{-1}, i.e. slightly larger than the stated uncertainty[12]. In addition, the pH of the return water fluctuates, indicating clear downhole reactions (probably with cement in some cases – e.g. sample 4-re-3 with a pH of 11.21). In the end, this is irrelevant as no tracer check was carried out on most of the groundwater samples, only on the last three samples, 4-pu-4-1 – 3. As such, all the others are Category 4 and only samples 4-pu-4-2 and 4-pu-4-3 are Category 3 owing to low levels of drilling tracer (6.9 and 7.0% respectively) and stable pH values (field versus laboratory). Only one sample 4-pu-4-3 has an incomplete set of environmental isotope data and an incomplete microbial sample set. In addition, the time series is also inadequate (not quite two months).

*Note that reporting the field pH values to three significant figures is meaningless as most field electrodes are correct to ±0.1 pH units.

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that chlorinity and stable isotopic data are available for most samples and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. The porewater data would thus all plot as Category 4. Several samples have adjacent groundwater data (i.e. 4-co-5, 4-co-8, 4-co-9 and 4-co-10), although the last two are associated with a rather large groundwater sampling interval.

2.2.5 Borehole HDB-5

(1) Surface/shallow waters

The surface waters have a full set of analyses (apart from environmental isotopes) but only a short time series (just less than five months) and so could be assigned to Category 4 (pending a charge balance check). There is no laboratory check on the field pH data.

(2) Deep groundwaters

Series 5-pu-1-1 to 5-pu-5-3

The return water tracer concentration varies between 8.1 and 11.2 mgL^{-1}, i.e. well exceeding the stated uncertainty[12]. In addition, the pH of the return water fluctuates, indicating clear downhole reactions (probably with cement in some cases). In the end, this is irrelevant as no tracer check was carried out on most of the groundwater samples. As such, all are Category 4. Five samples (i.e. 5-pu-1-4, 5-pu-2-4, 5-pu-3, 5-pu-4-3 and 5-pu-5-3) have an incomplete set of environmental isotope data and only three of these (5-pu-1-4, 5-pu-4-3 and 5-pu-5-3) have an incomplete microbial sample set. In addition, the time series is also inadequate for each section (5-pu-1-1, just over one day; 5-pu-2-1, less than one day; 5-pu-3, one day; 5-pu-4-1, just over one day; 5-pu-5-1, 2.5 days).

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that Cl^- and stable isotopic data are available for most samples and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. The porewater data would thus all plot as Category 4. Several samples have adjacent groundwater data (i.e. 5-co-4, 5-co-5 and 5-co-8).

2.2.6 Borehole HDB-6

(1) Surface/shallow waters

The surface waters have a full set of analyses, but no environmental isotopes, and a reasonable time series (11 months). There is no laboratory check on the field pH data and so could be assigned to Category 4.

(2) Deep groundwaters

Series 6-pu-1 to 6-pu-4-7

The return water tracer concentration varies between 8.55 and 11.06 mgL^{-1}, i.e. greater than the stated uncertainty[12]. There has also been no laboratory check on the samples' pH or EC and so all samples, apart from 6-pu-3 and 6-pu-4-7, are Category 4. Samples 6-pu-3 (8.1% drilling fluid) and 6-pu-4-7 (6.2%) also have more-or-less complete analyses, including environmental isotopes and microbes, and are therefore Category 3.

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that Cl^- and stable isotopic data* are available for all samples and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. The porewater data would thus all plot as Category 4.

2.2.7 Borehole HDB-7

(1) Surface/shallow waters

The surface waters have a full set of analyses and a short time series (six months). There is no laboratory check on the field pH and EC data and so could be assigned to Category 4. Two samples (7-ri-1 and 7-ri-4) have partial environmental isotope analyses.

(2) Deep groundwaters

The return water tracer concentration varies between 8.86 and 10.91 mgL^{-1}, i.e. slightly larger than the stated uncertainty[12]. Unfortunately, there is no groundwater samples are available from borehole HDB-7.

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that Cl^- and stable isotopic data are available for all samples and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. The porewater data would thus all plot as Category 4. Unfortunately, no groundwater samples are available from borehole HDB-7 for comparison with the porewaters.

* Some data have been noted as having a value and being N.D. at the same time (for example $^{36}Cl/Cl$ for 6-co-7 and 6-co-9) and this must be checked.

2.2.8 Borehole HDB-8

(1) Surface/shallow waters

The surface waters have a full set of analyses and a short time series (just less than six months). There is no laboratory check on the field pH and EC data and so could be assigned to Category 4. One sample 8-ri-1-5 has a partial environmental isotope analyses.

(2) Deep groundwaters

The return water tracer concentration varies between 9.40 and 10.82 mgL^{-1}, within the stated uncertainty[12]. All sample have drilling tracer contents >10% (14.7 to 100%, within uncertainty) and so are Category 4. This is unfortunate as all samples have basically complete analyses and two (8-pu-1 and 6-pu-2-6) have partial environmental isotope analyses, although the time series is very short for both borehole intervals (two and three days respectively).

(3) Porewaters

The fact that the porewaters have not been assessed for drilling fluid interaction should relegate them to Category 4 immediately (and the obvious oxidation effects to Category 3). However, more crucial here is the fact that Cl^- and stable isotopic data are available for all samples and, while the data are of immense value, they are degraded by the fact that there is no possibility of assessing drilling fluid effects on these conservative tracers. Thus, the porewater data would all plot as Category 4. One porewater sample, 8-co-1, has an associated groundwater sample.

2.3 Inter-operator comparison

In a national programme as large as that of Japan's, numerous people may be involved in a site characterisation – indeed, with the volunteer approach by the Nuclear Waste Management Organization of Japan (NUMO), it is conceivable that more than one site may be under investigation at any one time. As such, it is likely that several people may be involved in the hydrochemistry QA categorisation, making it important to assess potential inter-operator variability. This is well known from laboratory inter-comparisons[13] and can be minimised by following strictly controlled procedural guidelines. Here, preliminary plans include utilisation of argumentation networks[14] to minimise the degree of 'expert judgement' currently employed and the results of these changes will be published in due course. It is hoped that this will increase transparency in the data handling and so increase all stakeholders' confidence in both the data set itself, but also in the results obtained using such data for a repository site characterisation.

This weakness in the approach by the Swedish Nuclear Fuel and Waste Management Company (SKB) has not been noted before and would appear to be due to the employment of the same expert team throughout the duration of the recent Swedish site characterisation programme (J.A.T. Smellie, personal communication). As such, inter-operator variability was not an issue. In the Horonobe programme, this was checked by means of a small inter-comparison exercise and minor differences were noted[15].

3. Formalisation of field manual

This field manual has been developed in such a manner that field staff can use it as a quick-look tool whilst on station at a drill site[16]. As such, it has been deliberately kept to two sides of A4 paper – i.e. one sheet of paper that can be placed in a trouser, shirt or overall pocket for ease of access – and this is presented in Appendix 1. However, it is also necessary to explain some of the details of the procedures for the field staff and so more detailed 'background notes' have also been produced and these are presented in Appendix 2 (with supporting documentation on colloids in Appendix 3).

As part of the QMS, it is necessary to keep a 'paper trail' of changes to the field manual, so that any changes can be recorded with an explanation of the changes provided by the QMS manager. Here, following the parlance of the software industry, the following terminology has been adopted: the five versions of the field manual and the four versions of the background notes developed over this financial year should be seen as the "beta" versions and the versions included here as a "release candidate" as these versions were upgraded following field testing at Horonobe by National Institute of Advanced Industrial Science and Technology (AIST) and Japan Nuclear Energy Safety Organization (JNES). These will be numbered Release candidate 1 (RC1), Release candidate 2 (RC2) etc in the future, starting from here (N.B. Beta version 5 of the field manual is now RC1 in this parlance).

The quality of hydrochemical data can be influenced by several processes[3),16)–19)], including:

- contamination of the groundwater by drilling fluids or additives and by the material of the drilling equipment:
  - this will dilute the groundwater solutes;
  - additives, such as bentonite, will change the major element chemistry;
  - metals from the drill bit and lines can change the perceived redox state;
  - oxidants/reductants in the drilling fluid can change the perceived redox state.
- damage to the host rock by the physical/chemical process of drilling, which will cause:
  - production of large colloid populations, for example, when weak rock is badly damaged by the drill bit;
  - dissolution of highly soluble phases such as calcite, gypsum etc.
- alteration of the *in situ* conditions during sampling:
  - by the introduction of contaminants such as oxygen and other oxidants (trapped in or on sampling equipment) which changes the *in situ* redox conditions;
  - by degassing groundwater samples as they are brought to the surface, so changing pH and Eh values;
  - by oxidising reduced species during rock matrix sample handling and squeezing;
  - by pumping at too great a rate for the local groundwater 'reservoir' in the vicinity of the sampling point. This can induce draw-in of groundwater from further afield and mixing with the *in situ* groundwater to produce a sample which in non-representative of that horizon in the borehole;

  - by introducing surface microbes or additional nutrients. This will change the *in situ* microbial populations and, as a consequence, the redox state of the groundwater.
- contamination during sample handling by the introduction of atmospheric gases or other contaminants from the equipment (e.g. from sample filters) or from sloppy handling procedures.
- contamination during sample transport and storage by the introduction of atmospheric gases or other contaminants: this can be especially problematic for core samples if they are not adequately protected.
- contamination during analysis by the introduction of atmospheric gases or other contaminants from the equipment or analyst (e.g. trace levels of Sr from sweat can be transferred to equipment from hands if gloves are not worn).
- imprecise or inaccurate analysis, which is caused:
  - by equipment drift during analysis;
  - or by the use of inappropriate standards (e.g. with a significantly different matrix from that of the groundwater);
  - or by 'non-standard' groundwater matrices (e.g. brines etc.);
  - or by operator variability.

This field manual has attempted to address these processes by including:

- protocols for sampling (why, when and how);
- use of appropriate sampling equipment for the required task – when downhole, when on surface;
- field measurements and analysis (when are they necessary?);
- sample handling (what to be aware of, when to manipulate samples before storage, what not to do...);
- storage and transport;
- data handling and interpretation;
- definition of analytical programmes – how much do you need to measure, when and on what samples;
- laboratory QA – making sure that your staff understand uncertainties, error propagation and statistical significance;
- data manipulation – before diving head first into 'modelling', carry out preliminary data quality assessment and manipulations (see Chapter 2).

The main thrust behind the development of the field manual is that an appropriate QMS for site characterisation will save on effort by reducing errors and the requirement to re-sample and re-analyse samples. However, an inappropriate QMS not only wastes time and money by giving the staff additional (or wasted) effort, it can provide an unwarranted confidence in the data ("…it is quality assured, so it must be OK..."). Here, it has been the intention to avoid waste and keep it simple for the field operator.

4. Conclusions

This report details two quite different parts of the Horonobe URL QMS, but they are related insofar that the aim of both is to minimise wasted effort.

4.1 QA of hydrochemical data set

Part of a site characterisation hydrochemistry data set is presented here, as part of the evaluation of the palaeohydrogeological evolution of the Horonobe URL area. As there are many more porewater than groundwater data for the site, these porewater data are currently a more significant part of the site characterisation toolkit. As such, it makes sense to apply a similar QA regime to both sample and data sets, a novel approach for rock matrix porewaters. It is emphasised that an appropriate QMS for site characterisation will save on effort by reducing errors and the requirement to re-sample and re-analyse – but this can only be guaranteed by continuously assessing if the QMS is truly fit-for-purpose and amending it where necessary. For example, as the original groundwater QA system was specifically developed for the fractured crystalline rocks of the Fennoscandian Shield, it is likely that there will be procedural differences when applying the newly developed porewater system to the sedimentary rocks of the Horonobe area and these will be reported in the future.

Not surprisingly, most of the data examined here have been assigned a low category, simply because the samples were collected during drilling and hydraulic tests. As is well known[9), 20), 21)], such samples are almost invariably of lower quality than those taken after a borehole has had months to years to recover from the massive disturbances inflicted by the drilling and hydraulic testing procedures. Indeed, SKB have stated "For a representative hydrochemistry sample, it is vital, for example, that no significant hydro-testing has occurred in the hole beforehand as it may take days to years for the groundwater to recover its original state." To date, no such samples are available from the Horonobe site, but it is hoped that this will be rectified in the near future. In comparison, the vast majority of SKB's data from the recently completed Forsmark and Laxemar site characterisation are Category 3–5[20)]. Indeed, for redox sensitive species, less than 10% of the data are Category 1 or 2. In a review of the hydrochemistry programme in 2006, Bath and Hermansson[22)] noted that "…the success record of achieving complete sets of reliable data has so far been rather low", showing that JAEA's experience in Horonobe is far from unique. The same picture emerged when Posiva carried out a similar exercise on their Olkiluoto data recently, only just over 20% of the hydrochemistry samples were assessed as Category 1 or 2 (equivalent)[23)]. However, this does not mean that the data are worthless, far from it. As noted in Kunimaru et al.[3)] "At this point in a site characterisation, it is normal to have only low category data such as those discussed here, but these nevertheless provide the basis for building the preliminary site conceptual model. These data will be supplemented shortly by higher category data as samples are obtained from the finished boreholes which have had enough time since drilling and hydraulic testing to return to their near-pristine state.

However, the existing data will not be superseded by the new, higher category, data, they will remain as supporting information which can add weight to proposed trends in the groundwater chemistry, for example. " But this exercise does show that the current dataset, whilst appropriate for the earliest stages of a site characterisation, would not be of use for safety assessment related calculations for the site. These lessons should be noted by both the regulators and implementers in Japan.

An already planned improvement is to reduce dependence on expert judgement as experience here (see Chapter 2) has already shown operator-dependent differences in QA categorisation of the same datasets. This weakness in the SKB approach has not been reported before and would appear to be due to the employment of the same expert team throughout the duration of the recent Swedish site characterisation programme (J.A.T. Smellie, personal communication), so avoiding inter-operator differences. Preliminary plans include utilisation of argumentation networks[14] to minimise the degree of 'expert judgement' currently employed and the results of these changes will be published in due course. It is hoped that this will increase transparency in the data handling and so increase all stakeholders' confidence in both the data set itself, but also in the results obtained using such data for a repository site characterisation.

4.2 Formalisation of field manual

The RC1 version of the Horonobe field manual (and supporting background notes) have been presented here[11), 16)]. The short-term aim is to propose a QMS for on-site sampling, laboratory analysis and data interpretation for the Horonobe URL and the long-term aim is to develop a system for use in the national programme *before* it begins in earnest.

The current field manual includes:

- protocols for sampling (why, when and how);
- use of appropriate sampling equipment for the required task – when downhole, when on surface;
- field measurements and analysis (when are they necessary?);
- sample handling (what to be aware of, when to manipulate samples before storage, what not to do....), storage and transport.

Future work will cover laboratory practices, for example:

- definition of analytical programmes – how much needs to be measured, when and on what samples?
- laboratory QA – make sure that staff understand uncertainties, error propagation and statistical significance.
- analytical methods: as these vary slightly from laboratory to laboratory so 'round robin' comparisons must be carried out and laboratory practices formally quality-

assured (QAd) – especially if different methods are used to measure the same parameter.
- analytical operator: in many techniques, an operator bias can be clearly seen and this must also be taken into account.
- error calculations: it is a disturbing fact that few people really understand error propagation and, to avoid such problems, it is better to devise a common QAd methodology to be used by all analytical laboratories involved.
- sample QA procedures (which should cover most of the above but also include traceability of the sample, analytical procedures and so on).

In addition, for data manipulation, future work includes:

- a fully controlled raw data storage system (such as SKB's SICADA hydrochemistry database) is necessary.
- QAd data is included with a 'history' of the samples and connections to the background data (drilling reports etc).
- the system should be web-based to allow use of up-to-date data manipulation and data linking practices.
- access must be through an appointed database manager (DM).
- no data may be entered, changed or withdrawn without DM's permission.
- database is NOT an organic system – i.e. it is not allowed to 'evolve', rather it is frozen periodically and dated. For example, before a new borehole sampling/data production campaign (cf. Horonobe hydrochemistry Data Freeze I & II).

It has been argued that R&D organisations such as JAEA require no such QMS but this ignores several facts. First, as a proper QMS only improves efficiency and the standard of science produced, there can be no serious argument against even R&D organisations using one. Second, as noted in Ota et al.[7] "JAEA's viewpoint is that any URL site characterisation process should be used as the ideal training ground for the development of appropriate repository site characterisation methods, exploration tools and technical teams." As it is clear that any repository project requires a QMS[4], then it is wholly appropriate to begin the development of the repository site characterisation system in the URL project.

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References

1) ANRE and JAEA (2006): Research and Development Programme for the Geological Disposal of HLW, December 2006. ANRE, Tokyo and JAEA, Tokai, Japan. (in Japanese)
2) Ota, K., Abe, H. and Kunimaru, T. (Eds.) (2010): Horonobe Underground Research Laboratory Project, Synthesis of Phase I Investigations 2001–2005, Volume "Geoscientific Research". JAEA-Research 2010-068, JAEA, Tokai, Japan.
3) Kunimaru, T., Ota, K., Yamamoto, H. and Alexander, W.R. (2010): Groundwater/ Porewater Hydrochemistry at Horonobe URL: Data Freeze I – Preliminary Data Quality Evaluation for Boreholes HDB-9, 10 and 11. JAEA-Research 2010-035, JAEA, Tokai, Japan.
4) IAEA (2003): Site Evaluation for Nuclear Installations. IAEA Safety Standards Series, Safety Requirements No. NS-R-3, IAEA, Vienna, Austria.
5) IAEA (1996): Application of Quality Assurance to Radioactive Waste Disposal Facilities. IAEA TECDOC 895, IAEA, Vienna, Austria.
6) Alexander, W.R., McKinley, L.E. and McKinley, I.G. (2007): A Look to the Future, Chapter 10 in Alexander, W.R. and McKinley, L.E. (Eds.), Deep Geological Disposal of Radioactive Waste. Elsevier, Amsterdam, The Netherlands.
7) Ota, K., Kunimaru, T. and Alexander, W.R.: A novel quality assurance programme for rock matrix porewaters: an example from JAEA's Horonobe underground research laboratory, Japan. (submitted)
8) Ota, K., Alexander, W.R., Niizato, T. and Kunimaru, T. (2009): Evolution of the hydrochemical system at Horonobe, Japan: An indication from rock matrix porewater chemistry. Goldschmidt Conference, Abstracts 2009, Geochimica et Cosmochimica Acta, 73, Issue 13, Supplement 1, A980.
9) Laaksoharju, M., Smellie, J., Ruotsalainen, P. and Snellman, M. (1993): An Approach to Quality Classification of Deep Groundwaters in Sweden and Finland. SKB Report TR-93-27, SKB, Stockholm, Sweden.
10) Smellie, J.A.T., Tullborg, E-L. et al. (2008): Explorative Analysis of Major Components and Isotopes. SDM – Site Forsmark. SKB Report R-08-84, SKB, Stockholm, Sweden.
11) Kunimaru, T., Ota, K. and Alexander, W.R. (2009): Horonobe Underground Research Laboratory Project – Quality assurance audit of hydrochemical data from surface-based investigations Proceedings of the Annual Meeting of the Atomic Energy Society of Japan, 23–25 March 2009, Tokyo, Japan, p.209, AESJ, Tokyo, Japan. (in Japanese)
12) Kunimaru, T., Shibano, K., Kurikami, H. and Hara, M. (2007): Analysis of Ground Water from Boreholes, River Water and Precipitation in the Underground Research Laboratory Project. JAEA-Data/Code 2007-015, JAEA, Tokai, Japan. (in Japanese with English abstract)
13) WMO (2004): World Meteorological Organization Global Atmosphere Watch. No. 160, Manual for the GAW Precipitation Chemistry Programme: Guidelines, Data Quality Objectives and Standard Operating Procedures. WMO TD No. 1251, World Meteorological Organization, New York, USA.

14) Liu, X., Zheng, M., Venayagamoorthy, G.K and Leu, M. (2007): Management of an intelligent argumentation network for a web-based collaborative engineering design environment. Proceedings of the International Symposium on Collaborative Technologies and Systems, 21–25 May 2007, Orlando, USA. CTS 2007, pp.9–15, doi:10.1109/CTS.2007.4621732.
15) Kunimaru, T., Ota, K., Amano, K. and Alexander, W.R. (2010): Development of the quality management system for rock matrix porewaters sampled during surface–based investigations. Proceedings of the 2010 Annual Meeting of the Atomic Energy Society of Japan, 29–31 March 2010, Mito, Japan, p.408, AESJ, Tokyo, Japan. (in Japanese)
16) Ota, K., Kunimaru, T. and Alexander, W.R. (2009): Horonobe Underground Research Laboratory Project – Formalisation of a field manual for quality assurance for hydrochemical sampling. Proceedings of the 2009 Annual Meeting of the Atomic Energy Society of Japan, 23–25 March 2009, Tokyo, Japan, p.210, AESJ, Tokyo, Japan. (in Japanese)
17) Haug, A. (1985): Feldmethoden zur Grundwasserentnahme aus Tiefbohrungen und zur Hydrochemischen Überwachung der Bohrspülung. Nagra Technical Report NTB 85-07, Nagra, Wettingen, Switzerland. (*in German with English abstract*)
18) Nilsson, A-C. (2008): Analytical uncertainties. In: Kalinowski, B.E. (Ed.) Background Complementary Hydrogeochemical Studies. SDM-Site Forsmark, SKB Report R-08-87, SKB, Stockholm, Sweden.
19) Krachler, M. and Shotyk, W. (2008): Trace and ultratrace metals in bottled waters: Survey of sources worldwide and comparison with refillable metal bottles. Science of the Total Environment, 407, pp.1089–1096.
20) Laaksoharju, M., Smellie, J., Tullborg E-L., Gimeno, M., Gurban, I., Hallbeck, L., Molinero, J., Waber, N. (2008): Bedrock Hydrogeochemistry Forsmark. Site Descriptive Modelling. SDM-Site Forsmark. SKB Report R-08-47, SKB, Stockholm, Sweden.
21) Alexander, W.R., Berry, J.A., Kelly, M.J. and Swanton, S. (2011): Review of Colloids in the Geosphere and their Treatment in Performance Assessment, Report to NDA-RWMD, Serco/TAS/002924/01, Serco, Didcot, UK.
22) Bath, A. and Hermansson, H-P. (2007): INSITE Field Technical Review: Field Geochemistry Activities at SKB's Forsmark Site. SKI-INSITE TRD-07-03, SKI, Stockholm, Sweden.
23) Pitkänen, P., Ahokas, H., Ylä-Mella, M., Partamies, S., Snellman, M. and Hellä, P. (Eds.) (2007): Quality Review of Hydrochemical Baseline Data from the Olkiluoto Site. Posiva 2007-05, Posiva, Olkiluoto, Finland.

Appendix 1:

JAEA hydrochemistry QA system – Field manual (Release candidate 1, 26 Jan. 09)

0 Cleanliness and speed

Task: biggest problem for groundwater (and core) samples is contamination. This can be avoided by careful sampling and sub-sampling and more importantly by speedy handling methods. These sampling protocols are designed to minimise contamination.

1 Borehole log

Task: maintain a full record of borehole events and drill site activities at all times (using standard JAEA continuous monitoring system and CRIEPI-type spread sheet).

2 Drilling-related processes

2a Initial chemistry of drilling fluid

Task: water source (groundwater or river water *etc*) must be sampled and analysed before commencement of drilling (**water sampling protocol I)**. Samples must also be taken immediately following the initial addition of any drilling additives – only additives with a full analysis may be added (**water sampling protocol I after tank is fully mixed**).

2b Subsequent chemistry of drilling fluid

Task: sampling when a new supply of drilling water is delivered to the storage tank (**water sampling protocol II**).

2c Maintenance of drilling fluid tracer concentration

Task: drilling fluid tracer concentrations must be kept within **±10%** during drilling. Sampling and analysis of the tracer content of the circulating drilling fluid should be done hourly on-site during drilling. Use quick-look table to define mass of tracer required and dose storage tank appropriately. Ensure tank is thoroughly mixed. As a rule, the adjustment must be done immediately before (re)starting drilling and drilling should be suspended during the adjustment.

2d Maintenance of constant EC of drilling fluid

Task: in case of significant change in the drilling fluid TDS (owing to interaction with cuttings and/or mixture with groundwater with higher TDS), the drilling fluid 'chemistry' will be managed by adjusting the drilling fluid EC periodically – only additives with a full analysis may be added. Use quick-look table to dose storage tank appropriately.

2e Chemistry of the return fluid

Task: ensure that an aliquot of the return fluid flow is directed through on-line flow cell equipped with a data logger. Periodic sampling of the return fluid (**water sampling protocol II**) is obligatory.

2f Rock matrix core sampling

Task: collect relevant rock matrix cores, placing emphasis on speed to prevent oxidation of cores (**core sampling protocol I**).

2g Record of drilling fluid loss/gain

Task: maintain a balance of the mass of drilling fluid lost and/or gained during drilling. Record is obligatory as part of the borehole log.

3 Hydraulic testing-related sampling

Task: sampling of any return waters available during hydraulic testing (**water sampling protocol II**). See also comments in 4a, below.

4 Hydrochemical sampling

4a Installation of down-hole measurement cells and monitoring

Task: if at all possible, install down-hole measurement cells in packed-off intervals to begin assessment of groundwater stability. This should be done as soon as possible after hydraulic tests *etc* are completed.

4b Sampling flow rates

Task: to avoid disturbing the hydraulic/hydrochemical conditions, do not pump at too high a rate. Use quick-look table to define appropriate pumping rates for the specific packed-off intervals.

4c Assessment of representativity of the samples

Task: use down-hole measurement cells (if unavailable, ensure that an aliquot of the return water flow is directed through on-line flow cell equipped with a data logger). Time series sampling of pumped water (**water sampling protocol II**) is obligatory.

4d High category samples

Task: ensure that an aliquot of the return water flow is directed through on-line flow cell equipped with a data logger. Periodic sampling of pumped groundwater (**water sampling protocol III**) is obligatory.

4e Colloids and microbiology samples

Task: ensure that an aliquot of the return water flow is directed through on-line flow cell equipped with a data logger. Rare sampling of pumped groundwater (**water sampling protocol IV**) is applied. Note that it is essential to collect samples for the full spectrum of hydrochemical analysis at the same time, not just the colloid and microbiology samples. The protocols noted here are the minimum necessary to obtain some form of oversight of the in situ colloid and microbial populations.

採水調査における現場品質マニュアル
【現場シート】

（2009 年 1 月 26 日改定）

0. きれいさと速さ

採水調査においては，地下水（およびコア）試料の掘削水による汚染が最大の問題となる。これは細心の注意を払った試料の採取方法，試験・分析用試料の抽出方法，さらに重要なことは，より迅速な試料の取り扱い方法を確立することによって低減することができる。

1. ボーリング調査の記録

ボーリング調査の期間中は，現場における作業およびボーリング孔の掘削作業についてもれなく記録することが必要である。この際，現有の掘削モニタリングシステムや記録シートなどを活用する。

2. ボーリング孔の掘削に関連するプロセス

2a. 掘削水の初期の水質確認

掘削に使用する水（地下水または河川水など）は，ボーリング孔の掘削を開始する前に必ず採取し分析する（採水手順書Ⅰを参照）。また，掘削水は，泥剤や試薬などを添加した直後（タンク中の掘削水が均一に混合した後）に必ず採取し分析する（採水手順書Ⅰを参照）。なお，添加物は化学組成が明らかにされているものだけを用いること。

2b. 掘削水の補給時の水質確認

掘削水を貯蔵タンクに供給した際にも採水と分析を実施する（採水手順書Ⅱを参照）。

2c. 掘削水のトレーサー濃度の管理

ボーリング孔の掘削中は，掘削水のトレーサー濃度を指定した濃度の±10%以内で必ず管理する。具体的には，ボーリング孔内を循環させる掘削水を 1 時間毎に採取してトレーサー濃度を測定する。トレーサーを添加する際は事前に作成した早見表を用いてトレーサーの量を決定し，トレーサーの添加後はタンク中のトレーサー濃度を完全に均一にすること。トレーサー濃度は掘削を開始（再開）する直前に調整し，トレーサー濃度の調整中は掘削を必ず停止すること。

2d. 掘削水の電気伝導度の管理

掘削水の水質（総溶存成分濃度）は，掘削中に生じるカッティングスとの反応，総溶存成分濃度の高い地下水との混合によって変化するため，定期的に掘削水の電気伝導度を調整することによって管理する。泥剤や試薬を加える際は，事前に作成した早見表を用いること。

2e. 掘削リターン水の水質確認

掘削リターン水の一部は，データロガーを装備したフローセルに直接引き込む。掘削リターン水についても定期的な採水と分析を必ず実施する（採水手順書Ⅱを参照）。

2f. 基質部のコア試料の採取

対象となる基質部のコア試料を採取する際は，コアの酸化を防ぐためにコアの回収後，迅速かつ適切に作業を行う（コア採取手順書Ⅰを参照）。

2g. 掘削水の増減の記録

ボーリング孔の掘削中には掘削水の増減のバランスを管理する。この記録はボーリング調査の記録の一部として必要である。

3. 水理試験中に行う採水

水理試験中の揚水を採取する（採水手順書Ⅱを参照）。この際，後述（4a）のコメントを参考にすること。

4. 地球化学調査のための地下水試料の採取

4a. 原位置計測装置の設置とモニタリング

可能であるならば，調査区間に原位置計測装置を設置して，採水時の水質の安定性を評価する。なお，この作業は水理試験などが終了した直後に実施すること。

4b. 採水時の揚水量の設定

調査区間の周囲の水理場や地下水の地球化学特性の擾乱を避けるために，採水時の揚水量が極端に大きくならないように設定する。事前に作成した早見表を用いて，調査区間における適切な揚水量を設定すること。

4c. 地下水試料の代表性の評価

原位置計測装置を使用して水質の安定性を評価する。使用できない場合には，揚水の一部をデータロガーを装備したフローセルに直接引き込むこと。揚水試料は，揚水の開始時点から水質が安定するまで，必ず時系列を考慮して採取する（採水手順書Ⅱを参照）。

4d. 高品質の地下水試料の採取

地下水試料の採取は必ず繰り返し実施する（採水手順書Ⅲを参照）。この際，揚水の一部をデータロガーを装備したフローセルに直接引き込み，水質の安定性を確認すること。

4e. コロイド・微生物調査のための地下水試料の採取

地下水試料の採取は，揚水の一部をデータロガーを装備したフローセルに直接引き込んだ上で実施する（採水手順書Ⅳを参照）。採水の繰り返しは必要ないが，この採水時には，全項目の水質分析のための地下水試料も同時に採取する必要があることに留意する。また，ここに記した示した手順は，採水に伴う可能性のある擾乱を評価することにより，原位置のコロイドおよび微生物に関するデータの品質を確認するための必要最小限のものである。

Appendix 2:

JAEA hydrochemistry QA system – Field manual background notes (Release candidate 1, 26 Jan. 09)

An appropriate QA system for site characterisation will save on effort by reducing errors and the requirement to re-sample and re-analysis – but this can only be guaranteed by continuously assessing if the QA system is truly fit-for-purpose and amending it as necessary based on the practical experience of the end-users on site.

1 Borehole log

Maintain a full record of borehole events and drill site activities at all times as this allows the potential impact of a range of processes and mechanisms to be evaluated at a later date. This must include any non-standard incidents and/or accidents in the incident file of the log. Until a dedicated system can be arranged, use the standard JAEA continuous monitoring system and a spread sheet in Excel® format.

2 Drilling-related processes

2a Initial chemistry of drilling fluid

Water source (groundwater or river water) must be analysed before commencement of drilling and whenever the storage tank is refilled. Samples must be taken immediately following the addition of any drilling additives (see below). Very first analysis should be **water sampling protocol I**. For subsequent checks, pH, Eh etc will suffice (**water sampling protocol Ia**).

Drilling additives such as bentonite can only be used if they have been fully characterised (chemistry and mineralogy). Note that manufacturer's analysis may be acceptable if they have their own QA system (*eg* ISO *etc*) and if the analysis is full enough. Here 'full enough' means covering the same suite of parameters to be determined in **water sampling protocol IV**.

2b Subsequent chemistry of drilling fluid

Although the drilling fluid in the tank is a mixture of many processes, chemistry must be checked on new water input (NB each new delivery should be included in the borehole log) to prevent the drilling fluid chemistry from changing considerably (see section 2a, above).

2c Maintenance of drilling fluid tracer concentration

It is necessary to evaluate the degree of groundwater contamination with drilling fluid by quantifying tracer concentrations in sampled waters periodically. For the evaluation, the drilling fluid tracer concentrations must be kept within **±10%** during drilling. Sampling and analysis of the tracer content of the circulating drilling fluid should be done hourly on-site during drilling. Use quick-look table to define mass of tracer required and dose storage tank appropriately. Ensure tank is thoroughly mixed. As a rule, the adjustment is to be done immediately before (re)starting drilling and drilling to be suspended during the adjustment. Quick-look tables which lay out the amounts of tracer to be added (vary depending on the volume of the storage container *etc*) should be calculated in advance.

A rapid or significant change in the drilling fluid tracer concentration is an indicator for exchanging the drilling fluid. Work should be carried out on-site as quickly as practicable involving sampling and tracer analysis of the drilling fluid in order to take necessary actions without undesirable delay.

2d Maintenance of constant EC of drilling fluid

It is not possible to control every parameter of the drilling fluid, but the TDS (Total Dissolved Solids) is a reasonable 'bulk' value and worth managing as EC (Electrical Conductivity). EC control value should be defined based on the local geological and hydrochemical information available. Quick-look tables, established for each formation, structural domain or every 100 mabh section, will be drafted to cover the required actions.

2e Chemistry of the return fluid

The chemistry of the return water indicates if there are potential problems (*eg* lot of damage to the rock by the drill bit may release pulses of Cl from the porewater or Al from the rock). In addition, the samples provide a 'first look' at the local groundwater conditions. However, by their nature, these are highly disturbed samples and therefore do not require a detailed chemical analysis, hence **water sampling protocol II** will be sufficient.

2f Rock matrix core sampling

The current methodology is described in Kunimaru et al.[1)] and it clearly needs to be changed as all porewaters collected to date show signs of oxidation. This is partly due to the laboratory methods employed (dealt with in 'Support laboratory manual, version 1'), but the core handling methods also require updating. Thus it is recommended that the new **core sampling protocol I** should be used.

2g Record of drilling fluid loss/gain

Do we understand the disturbance caused by drilling fluid? The answer is currently "no". To improve this situation, it is therefore necessary to maintain a full record of the loss (and rare gain) of drilling fluid to assess the impact of drilling fluid on parameters such as redox sensitive elements and the effect of dissolution of major components in groundwater.

Further, when LCM (lost circulation material) steps are taken, detailed product information should be available from the producers.

3 Hydraulic testing-related sampling

By definition, these are hydrochemically disturbed samples and will always be of a low QA category (see discussion in Kunimaru et al.[1)] Nevertheless, in some boreholes, because hydrochemical sampling during hydraulic testing is convenient, these may be the only samples available for chemical analysis and so remain important. If this is the case, a time series should also be collected if possible.

However, the disturbed nature of the samples means that **water sampling protocol II** will be sufficient.

4 Hydrochemical sampling

4a Installation down-hole measurement cells and monitoring

This is international best practice (*eg* Pitkänen et al.[2)]; Smellie et al.[3)]) and is clearly preferable in such gas-rich groundwaters as are present at Horonobe. A surface flow cell is useful as a back-up, but monitoring by down-hole measurement cells must be employed as the primary source of the groundwater *in situ* pH/Eh.

4b Sampling flow rates

It is imperative that any sample is representative of the depth at which it is collected and does not represent a mixed water. This occurs when water is pumped for sampling at a rate which is too high for the sampled horizon and this leads to draw-down from above, draw-up from below and draw-in from the matrix and/or nearby fractures. There are several ways of assessing 'how much is enough': for example, in a poorly conductive zone, pumping rates should be similar to that defined during flow logging (*eg* Pitkänen et al.[2)], suggest no more than twice the flow logging value). As before, quick-look tables will be drafted to cover the required actions in each formation based upon past experience.

4c Assessment of representativity of the samples

There is little point in running full analyses until we are satisfied that disturbances from drilling have settled down and that we have the packers properly installed at the selected positions. Here, a time series of samples should be collected to assess the groundwater stability, remaining drilling fluid contamination and that no packer-bypass *etc* exist. Periodicity of sampling will depend on the situation, so begin weekly and see how things look. Better still would be to install the down-hole measurement cells for monitoring pH/Eh/EC/Temp and use these to define the stability before intensive groundwater sampling.

4d High category samples

These are labelled high category samples as they should not be collected until it is ensured that the best conditions for sampling have been established (see comments in 4a, above). Using **water sampling protocol III** samples have the possibility of providing redox data, but this needs to be tested on the first few samples to assess if the pumping and handling methods make this a meaningless exercise (highly likely).

4e Colloids and microbes

These samples should only really be taken once it is ensured that a system has been settled, but at least one sample should be analysed at the beginning of the 4a task would be useful to establish the baseline conditions during the disturbed period. Note that it is essential to use the colloid filtrate for the hydrochemical analysis to make any meaningful comparisons. Likewise, the microbial analysis should be made on filtered and unfiltered samples from the same sample set.

For the colloidal and microbial sampling, **water sampling protocol IV** must be used.

Water sampling protocol I (main analysis)

Container type	Split label	Pre-handling in the off-site lab	On-site procedure	Determinand(s)
PE: Polyethylene	F: filtered UF: unfiltered UA: unacidified (cf. HNO_3)	Labelling of sub-sample bottles, addition of reactants, place in labelled bag with syringe and filters		
Large mouthed 200 mL PE, with inlet valve in lid for water flow in and outlet valve for the displaced air			Collect sample directly from sampling line. Inside a portable fume hood, draw off sub-samples with 50 mL syringe, place 0.45 µm filter (in holder) *when required* and then syringe sub-samples directly into the containers. NB First 5 mL squeezed through the filter should be discarded. Change filter and holder for each different sample bottle	
50 mL PE	F/HNO_3/Cations	Add two drops of concentrated nitric acid to the empty container using a Pasteur pipette	Completely fill container with filtered sample	Cations
30 mL PE	F/UA/Anions		Completely fill container with filtered sample	Anions
30 mL PE	F/UA/Alkalinity		Completely fill container with filtered sample	pH, alkalinity, TIC and TOC
28 mL glass	UF/UA/Stable O+H		Completely fill container with **unfiltered** sample	Stable isotopes
Large mouthed 200 mL PE			Refill original bottle directly from sampling line. Measure pH, EC and Temp on sample. Dispose of sample afterwards	On-site pH, EC and Temp
			Place all bottles (apart from the reserve, below) in labelled plastic bag and store in fridge until analysis	
1000 mL PE	UF/UA/Reserve		Collect sample directly from sampling line. Completely fill container and place in separate plastic bag. Store in fridge until required	

Water sampling protocol Ia (routine main analysis)

Collect sample directly from tank in a plastic bottle. Draw off sub-samples for separate pH, Eh temperature and conductivity measurements. Save remaining water sample in a sealed and labelled plastic bottle in case further analysis is necessary. Samples to be maintained until the drilling QA-log is signed off and closed.

Water sampling protocol II (limited analysis)

Container type	Split label	Pre-handling in the off-site lab	On-site procedure	Determinand(s)
PE: Polyethylene	F: filtered UF: unfiltered UA: unacidified (cf. HNO_3)	Labelling of sub-sample bottles, addition of reactants, place in labelled bag with syringe and filters		
Large mouthed 200 mL PE, with inlet valve in lid for water flow in and outlet valve for the displaced air			Collect sample directly from sampling line. Inside a portable fume hood, draw off sub-samples with 50 mL syringe, place 0.45 µm filter (in holder) *when required* and then syringe sub-samples directly into the containers. Change filter and holder for each different sample bottle	
50 mL PE	F/HNO_3/Cations	Add two drops of concentrated nitric acid to the empty container using a Pasteur pipette	Completely fill container with filtered sample	Cations
30 mL PE	F/UA/Anions		Completely fill container with filtered sample	Anions
30 mL PE	F/UA/Alkalinity		Completely fill container with filtered sample	pH, alkalinity
28 mL glass	UF/UA/Stable O+H		Completely fill container with **unfiltered** sample	Stable isotopes
Large mouthed 200 mL PE			Re-fill original bottle directly from sampling line. Measure pH, EC and Temp on sample. Dispose of sample afterwards	On-site pH, EC and Temp
			Place all bottles (apart from the reserve, below) in labelled plastic bag and store in fridge until analysis	
1000 mL PE	UF/UA/Reserve		Collect sample directly from sampling line. Completely fill container and place in separate plastic bag. Store in fridge until required	

Water sample protocol III (full analysis, including redox)

Container type	Split label	Pre-handling in the off-site lab	On-site procedure	Determinand(s)
PE: Polyethylene	F: filtered UF: unfiltered UA: unacidified (cf. HNO_3)	Labelling of sub-sample bottles, addition of reactants, place in labelled bag with syringe and filters		
Large mouthed 200 mL PE, with inlet valve in lid for water flow in and outlet valve for the displaced air			Collect sample directly from sampling line. Inside a portable fume hood, draw off sub-samples with 50 mL syringe, place 0.45 µm filter (in holder) *when required* and then syringe sub-samples directly into the containers. NB First 5 mL squeezed through the filter should be discarded. Change filter and holder for each different sample bottle	
50 mL PE	F/HNO_3/Cations	Add two drops of concentrated nitric acid to the empty container using a Pasteur pipette	Completely fill container with filtered sample	Cations
30 mL PE	F/UA/Anions		Completely fill container with filtered sample	Anions
30 mL PE	F/UA/Alkalinity		Completely fill container with filtered sample	pH, alkalinity, TIC and TOC
30 mL PE	UF/NaOH/Sulphide	Add one pellet of NaOH to the empty container	Completely fill with **unfiltered** sample: NB this reaction is exothermic	Sulphide
28 mL glass	UF/UA/Stable O+H		Completely fill container with **unfiltered** sample	Stable isotopes
500 mL glass	UF/UA/^{3}H		Fill bottle with **unfiltered** sample leaving a small headspace (*ca* 25 mL)	Tritium
50 mL glass	UF/UA/Noble gases		Completely fill container with **unfiltered** sample	Noble gases
1000 mL gas-tight sampling flask	UF/UA/Gas	Use canister auto-cleaning system, evacuate the containers and fill it with inert gas. Repeat nine times to completely evacuate and clean containers	Collect sample directly from sampling line	Dissolved gases still remaining in groundwater at surface

Container type	Split label	Pre-handling in the off-site lab	On-site procedure	Determinand(s)
200 mL gas tight sampling flask	UA/Redox	Use canister auto-cleaning system, evacuate the containers and fill it with inert gas. Repeat nine times to completely evacuate and clean containers	Collect sample directly from sampling line. Must be analysed within six hours	Redox parameters
Large mouthed 1000 mL PE, with inlet valve in lid for water flow in and outlet valve for the displaced air			Collect sample directly from sampling line. Inside a portable fume hood, using a peristaltic pump and in-line 0.45 μm filter, fill the following containers. NB First 5 mL squeezed through the filter should be discarded. Change filter and holder for each different sample bottle	
1000 mL glass	F/NaOH/^{14}C	Add 5N-NaOH (10 mL) to container	Completely fill container with filtered sample, add 2N-$SrCl_2$ (10 mL) to induce $SrCO_3$ precipitation	^{14}C
1000 mL PE	F/NaOH/^{34}S	Add 5N-NaOH (1 mL) to container	Completely fill container with filtered sample, add 1N-$(CH_3COO)_2Zn$ (1.5 mL to induce ZnS precipitation	^{34}S
1000 mL glass	F/UA/^{13}C			^{13}C
5000 mL PE	F/UA/^{36}Cl			^{36}Cl
20 L PE container	F/UA/U-series			Natural decay series
Large mouthed 200 mL PE, with inlet valve in lid for water flow in and outlet valve for the displaced air			Re-fill original bottle directly from sampling line. Measure pH, EC and Temp on sample. Dispose of sample afterwards	On-site pH, EC and Temp
			Place all bottles (apart from the reserve, below) in labelled plastic bag and store in fridge until analysis	
20 L PE container	UF/UA/Reserve		Collect sample directly from sampling line. Completely fill container and place in separate plastic bag. Store in fridge until required	

Water sampling protocol IV (full analysis plus colloids and microbes) – see also Appendix 3

Container type	Split label	Pre-handling in the off-site lab	On-site procedure	Determinand(s)
PE: Polyethylene PP: Polypropylene	F: filtered UF: unfiltered UA: unacidified (cf. HNO_3)	Labelling of sub-sample bottles, addition of reactants, place in labelled bag with syringe and filters		
Connection from the sampling line to the colloid sampling system, gas-tight reservoir			Samples pumped through 0.45 μm and then 0.20 μm in-line filters. Filtrate is split between sample bottles below as normal. NB First 5 mL squeezed through the filter should be discarded. Whether filters should be changed or not for each sample bottle will depend on the colloid populations present and this must be tested first	Colloids
50 mL PE	F/HNO_3/Cations	Add two drops of concentrated nitric acid to the empty container using a Pasteur pipette	Completely fill container with filtered sample	Cations
30 mL PE	F/UA/Anions		Completely fill container with filtered sample	Anions
30 mL PE	F/UA/Alkalinity		Completely fill container with filtered sample	pH, alkalinity, TIC and TOC
30 mL PE	UF/NaOH/Sulphide	Add one pellet of NaOH to the empty container	Completely fill with **unfiltered** sample: NB this reaction is exothermic	Sulphide
28 mL glass	UF/UA/Stable O+H		Completely fill container with **unfiltered** sample	Stable isotopes
500 mL glass	UF/UA/^{3}H		Fill bottle with **unfiltered** sample leaving a small headspace (*ca* 25 mL)	Tritium
50 mL glass	UF/UA/Noble gases		Completely fill container with **unfiltered** sample	Noble gases
1000 mL gas-tight sampling flask	UF/UA/Gas	Use canister auto-cleaning system, evacuate the containers and fill it with inert gas. Repeat nine times to completely evacuate and clean containers	Collect sample directly from sampling line	Dissolved gases still remaining in groundwater at surface

Container type	Split label	Pre-handling in the off-site lab	On-site procedure	Determinand(s)
200 mL gas tight sampling flask	UA/Redox	Use canister auto-cleaning system, evacuate the containers and fill it with inert gas. Repeat nine times to completely evacuate and clean containers	Collect sample directly from sampling line. Must be analysed within six hours	Redox parameters
Large mouthed 1000 mL PE, with inlet valve in lid for water flow in and outlet valve for the displaced air			Collect sample directly from sampling line. Inside a portable fume hood, using a peristaltic pump and in-line 0.45 μm filter, fill the following containers. NB First 5 mL squeezed through the filter should be discarded. Change filter and holder for each different sample bottle	
1000 mL glass	F/NaOH/^{14}C	Add 5N-NaOH (10 mL) to container	Completely fill container with filtered sample, add 2N-$SrCl_2$ (10 mL) to induce $SrCO_3$ precipitation	^{14}C
1000 mL PE	F/NaOH/^{34}S	Add 5N-NaOH (1 mL) to container	Completely fill container with filtered sample, add 1N-$(CH_3COO)_2Zn$ (1.5 mL) to induce ZnS precipitation	^{34}S
1000 mL glass	F/UA/^{13}C			^{13}C
5000 mL PE	F/UA/^{36}Cl			^{36}Cl
20 L PE container	F/UA/U-series			Natural decay series
50 mL PP, γ-ray sterilised	UF/Formalin/M-TC		Soon after sampling, add neutral formalin to attain 4% of final concentration in order to fix the cell. Store the sample in fridge	Total bacteria
1000 mL gas-tight glass container	UF/UA/M-activity	Autoclave container at 121°C over 15 minutes and fill the container with inert gas (purity of 99.999%)	Collect sample directly from sampling line under anaerobic conditions to avoid contamination with oxygen. Keep the sample anaerobic with oxygen scavengers and store in fridge	Microbial activity
2000 mL PP	UF/UA/M-DNA	Autoclave container at 121°C over 15 minutes	Collect sample directly from sampling line. Samples should be through 0.20 μm in-line filter. Store the filter with microbial cells in freezer	Microbial communities (DNA analysis)

Container type	Split label	Pre-handling in the off-site lab	On-site procedure	Determinand(s)
Large mouthed 200 mL PE, with inlet valve in lid for water flow in and outlet valve for the displaced air			Re-fill original bottle directly from sampling line. Measure pH, EC and Temp on sample. Dispose of sample afterwards	On-site pH, EC and Temp
			Place all bottles (apart from the reserve, below) in labelled plastic bag and store in fridge until analysis	
20 L PE bottle	UF/UA/Reserve		Collect sample directly from sampling line. Completely fill container and place in separate plastic bag. Store in fridge until required	

Water sampling protocol V (alternative)

1) Use already cleaned and pre-labelled sample bottles
2) Bailing of the drilling fluid directly from the tank with a PE dipper
3) Washing of the cleaned sample bottles with the small amount of sampled fluid three times and filling of the bottles with the drilling fluid
4) Quick observation of the drilling fluid in the on-site laboratory; the following items to be checked and described: colour, smell, bubbles, suspension and precipitation
5) Filtration of the samples through a 0.45 μm pore sized filter immediately after the sampling in the on-site laboratory; no chemical treatment to be applied for the drilling fluid
6) Describing the following information on the label: borehole number, sample number, sampling date and time, sampling depth, name of sampling person and quick observation results
7) Storage of all the samples except for hourly collecting ones in the refrigerator in the on-site laboratory until chemical analysis

Timing and frequency

- Sampling of the initial drilling fluid to be done before drilling on-site
- Sampling of the circulated drilling fluid to be done hourly, daily and every 100 mabh drilling on-site; in case of continuous (24 hours) drilling, sampling to be scheduled at night and chemical analysis in the daytime
- In case of the preparation of drilling fluid with fresh water to refill the tank, the input water also to be sampled for both chemical analysis and storage

Place

- Sampling at the suction tank
- Treatment and storage of the samples in the on-site laboratory

Volume

- Obligatory to collect the following drilling fluid (and input water when used) samples:
  a) 100 mL hourly for tracer measurement
  b) 100 mL daily for storage (in a PE bottle)
  c) 1,000 mL daily for major component analysis
  d) 1,000 mL every 100 mabh drilling for stable isotope analysis
  e) 20 L every 100 mabh drilling for back-up storage (in a PE tank)

Core sampling protocol I

Several simple steps must be followed, with the emphasis on speed of handling. The entire process should take no longer than 10 minutes from core recovery to wax seal. Any delays must be noted in the borehole log. The standard on-site procedure of core description and photography will be carried out in the analytical laboratory's glovebox (cf. laboratory protocol).

1) upon core recovery, immediately wipe dry and photograph quickly
2) using either a stone saw, power chisel or air-cooled corer, remove the outer 15 mm of the core (NB previously 10 mm; see Charlton et al.[4])
3) wipe clean with a dry cloth
4) place in a aluminium-backed plastic bag, pump out any air (until bag is tight on the sample) with a small electric pump and heat seal the opening
5) repeat once more
6) tightly wrap in aluminium foil
7) dunk in wax to seal completely (see Figure 1)
8) transport to the laboratory and beginning of squeezing must occur within three days

Figure 1: Following sealing in two layers of aluminium-backed plastic and aluminium foil, the core will be sealed in wax until required for squeezing. From Ota et al.[5]

採水調査における現場品質マニュアル
【付属書】

（2009 年 1 月 26 日改訂）

地質環境調査・評価において適切な品質保証システムを整備・運用することにより，調査・評価におけるミスや再調査が必要となるような事態の低減を図ることができ，結果として調査・評価の効果的・効率的な実施につながる。このためには，品質保証システムが確実に目標に適合していることが継続的に確認されなければならず，また，ユーザーが現場で実際に適用した経験などに基づいて，適宜，改訂されることが求められる。

この付属書は，「採水調査における現場品質マニュアル・現場シート」の各項目に関する背景情報を記しており，併せて採水手順書Ⅰ～Ⅴとコア採取手順書Ⅰを添付している。

1. ボーリング調査の記録

ボーリング調査の期間中は，現場における作業およびボーリング孔の掘削作業についてもれなく記録する。これにより，様々な原因やプロセスによって生じると想定される影響を，後日，評価することができるようになる。ボーリング調査記録のファイルには，一般的や偶発的などにかかわらず，どのような事象や事故も必ず記録する。この際，ボーリング調査専用の記録システムが整備されるまでは，現有の掘削モニタリングシステムや記録シートを活用する。

2. ボーリング孔の掘削に関連するプロセス

2a. 掘削水の初期の水質確認

掘削に使用する地下水や河川水などは，ボーリング孔の掘削を開始する前，貯水タンクに補給する際，さらに，泥剤や試薬などを添加した直後にも必ず試料を採取し分析する。この際，最初の試料採取は採水手順書Ⅰに従って実施する。また，引き続き（繰り返し）行う水質確認の項目としては，pH，酸化還元電位，電気伝導度，温度で十分であり，この際の試料採取は採水手順書Ⅰａを参照する。

ベントナイトのような添加物は，化学組成や鉱物組成などが十分に明らかにされているものだけを用いる。その添加物の製造者が独自の品質保証システム（例えば，ISO 認証）を有しており，製造者による分析が採水手順書Ⅳに基づいて分析される全ての項目を網羅している場合は，製造者による分析結果を参照することもできる。

2b. 掘削水の補給時の水質確認

掘削水の水質は様々なプロセスを経て変化するが，掘削水の補給時にその水質が極端に変化することを防ぐためには，前述（2a）のとおり，補給する新たな地下水や河川水などについても水質の確認を必ず行うことが必要である。この際の試料採取は採水手順書Ⅱを参照する。なお，ボーリング調査記録に掘削水の補給についても必ず記録する。

2c. 掘削水のトレーサー濃度の管理

掘削水のトレーサー濃度を繰り返し測定することによって，掘削水による地下水の汚染の程度を把握することが必要である。このためには，ボーリング孔の掘削中は，掘削水のトレーサー濃度をあらかじめ規定した濃度の±10%以内で管理しなければならない。具体的には，ボーリング孔内を循環させる掘削水の採水とトレーサー濃度の測定を現場で 1 時間毎に行う。また，トレーサー濃度の調整のためにトレーサーを添加する際は，事前に作成した早見表を用いてトレーサーの量を決定し，添加作業を適切に行うとともに，タンク中のトレーサー濃度を完全に均一にする。

原則として，トレーサー濃度は掘削を開始（再開）する直前に調整し，トレーサー濃度の調整中は掘削を必ず停止させる。なお，添加するトレーサーの総量と濃度との関係（貯蔵タンクとの容量に依存する）を事前に計算し，早見表を準備しておくことが肝要である。

掘削水のトレーサー濃度の急激もしくは極端な変化は掘削水を交換する指標となる。この際，必要以上に遅れることなく対応をとるためには，掘削水の採水やトレーサー濃度の測定などの現場作業はできる限り迅速に行い，常に掘削水の状態を把握しておくことが肝要である。

2d. 掘削水の電気伝導度の管理

掘削水の全ての成分を管理することは不可能であるものの，掘削水の総溶存成分濃度は水質全体を代表する値であるため，これを電気伝導度で管理する手法が有効である。電気伝導度の管理基準値は，調査対象岩盤の地質学的および地下水の地球化学的特性に基づいて設定する。このためには，それぞれの岩盤・岩相や地質構造ユニットまたは掘削長 100m 毎に管理基準値を設定した早見表を準備し，必要な対応を取ることができるようにする。

2e. 掘削リターン水の水質確認

掘削リターン水の水質から，ボーリング孔の掘削に伴う地球化学的な擾乱（例えば，掘削用ビットによって著しい損傷を受けた岩石からのアルミニウムイオンの溶出，間隙水からの塩化物イオンの溶出の可能性）などを推測することができ，さらに，掘削深度の地下水の水質をこの時点でおおよそ推定することもできる。しかしながら，本質的に掘削リターン水は極めて汚染されているため，詳細な化学分析は必要としない。よって，採水手順書Ⅱの適用で十分である。

2f. 基質部のコア試料の採取

現行の手法は國丸ほか[1)]に示されているが，幌延深地層研究計画において採取された全ての間隙水試料について酸化の影響が認められたため，明らかに手法の見直しが必要である。試料の酸化は，実験室での間隙水の抽出手法（実験室マニュアル第 1 版を参照）にも起因するものの，コアの取り扱い方法が主な要因と考えられるため，その改善を図る必要がある。よって，新しいコア採取手順書Ⅰの適用が望ましい。

2g. 掘削水の増減の記録

現在，掘削水によって生じた地球化学的擾乱を正確に把握することは不可能である。この状況を改善するための一つの手段として，酸化還元に鋭敏な元素などに対する掘削水の影響および掘削水の主要成分が地下水中に溶出する影響を評価することが挙げられる。このためには，ボーリング孔の掘削中には掘削水の増減（ほとんどの場合は逸水による減少）のバランスを管理することが必要である。さらに，逸泥防止剤を用いた場合は，製造者から詳細な製品情報を入手する。

3. 水理試験中に行う採水

原則として，水理試験中に採取した地下水は，例外なく地球化学的に擾乱を受けた低品質の試料として取り扱われる（國丸ほか[1)]を参照）。それにもかかわらず，水理試験中の採水は効率的であり，地球化学調査のための唯一の地下水試料として採取されることが多いため，水理試験中に採取した地下水試料は重要な位置づけを有する。このような場合には，時系列（採水に伴う水質の時間変化）を考慮して採水を行う。しかしながら，地球化学的に擾乱を受けた試料であることから，この際の試料採取においては採水手順書Ⅱの適用で十分である。

4. 地球化学調査のための地下水試料の採取

4a. 原位置計測装置の設置とモニタリング

この方法は国際的に最良と考えられており（例えば，Pitkänen ほか[2]；Smellie ほか[3]），幌延のようなガスを溶存する地下水には適している。地上でのフローセルはその代替手法として役に立つが，原位置での地下水の pH と酸化還元電位の値としては，原位置計測装置によるモニタリングの値が用いられなければならない。

4b. 採水時の揚水量の設定

どの地下水試料にとっても，それが採水した深度を代表し，掘削水により汚染していないということが必ず求められる。これは，採水深度（調査区間）に対して十分に大きな揚水量で採水を行った場合に達成されるが，調査区間の上部では水位低下，調査区間の下部では水位上昇，調査区間においては基質部や近傍の割れ目からの地下水の引き込みが生じることも考慮しなければならない。採水時の揚水量が十分か否かを検討する考え方はいくつかあるが，例えば，透水性の悪い区間では，揚水量を流体検層で適用した量と同程度とする（Pitkänen ほか[2]は流体検層時の 2 倍を超えない揚水量を提案している）などがある。事前に作成した早見表を用いて，調査区間における適切な揚水量を設定する。

4c. 地下水試料の代表性の評価

掘削による擾乱が落ち着き，所定の位置にパッカーが正しく設置されたことが確認されるまで，全項目の水質分析を行ってはならない。水質の安定性，掘削水による残留汚染の程度，パッカー近傍での地下水の回り込みなどがないことを確認するためには，揚水の開始時点から水質が安定するまで，採水手順書Ⅱを参照し，必ず時系列を考慮して揚水試料を採取する。試料採取の間隔は調査区間の地質学的・水理学的条件によって異なるため，任意の間隔を設定し，どのような経時変化をたどるかを観察する。採水に当たっては，原位置計測装置を用いて pH，酸化還元電位，電気伝導度，温度をモニタリングし，調査区間の水質の安定性を評価することが望ましい。

4d. 高品質の地下水試料の採取

調査区間が本格的な採水に最も適した条件になったことが確認された以降，採取される地下水試料は高品質と位置づけられる（前述 4a を参照）。この際の試料採取は採水手順書Ⅲを適用し注意深く作業を行うことにより，地下水の酸化還元に関するデータを取得することもできる。ここで注意すべきことは，揚水による採水と地下水試料の取り扱い方法によっては，試料の品質を低下させる可能性がある（非常にありがちな）ことである。したがって，本格的な採水の開始直後の数試料は，その状態を評価するためのチェックが必要である。

4e. コロイド・微生物調査のための地下水試料の採取

調査区間が本格的な採水に最も適した条件になったことが確認された以降，コロイド・微生物調査のための地下水試料を採取する。この際，前述（4a）の原位置計測装置によるモニタリングの初期段階において最低 1 試料の分析を行い，地下水が汚染されている段階でのベースライン状態を把握しておくことが役に立つ。コロイド・微生物調査のためには，濾過した試料と無濾過の試料の両方を分析することによって，その結果に関する有意の比較を行うことが可能となる。コロイド・微生物調査のための採水には，採水手順書Ⅳを必ず適用する。

採水手順書Ⅰ（主要成分分析用試料）

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
PE:ポリエチレン	F: 濾過 UF:無濾過 UA:酸無添加	分析試料の容器にラベルを貼り付け，試薬を加えた後，分析試料をシリンジとフィルターとともにラベルを貼り付けたビニル袋に入れておく。		
大口径 200 ml PE ボトル（取水バルブ＋排気バルブ付）			採水装置のフローラインから試料を直接採取する。携帯ドラフトの中で 50 ml シリンジを用いて分析試料を採取し，容器の中に注入する。試料を分取する際，必要に応じて 0.45μm フィルター（ホルダーで固定）による濾過を行う。なお，濾液の最初の 5 ml は捨てる。異なる試料容器毎にフィルターとホルダーを交換する。	
50 ml PE ボトル	F/HNO_3/Cation	パスツール・ピペットを使って濃硝酸 2 滴を空の容器に加えておく。	濾過試料で両方の容器を完全に満たす。	陽イオン
30 ml PE ボトル	F/UA/Anion		濾過試料で容器を完全に満たす。	陰イオン
30 ml PE ボトル	F/UA/Alkalinity		濾過試料で容器を完全に満たす。	pH，アルカリ度，全無機炭素，全有機炭素
28 ml ガラス瓶	UF/UA/Stable O+H		無濾過の試料で容器を完全に満たす。	安定同位体
大口径 200 ml PE ボトル			採水装置のフローラインから再び試料を直接採取する。試料の pH，電気伝導度，温度を計測し，計測後，試料を廃棄する。	pH，電気伝導度，温度の現場計測
			ラベルを貼り付けたビニル袋に全ての分析試料の容器（保存試料は除外）を入れ，分析に供するまで冷蔵庫で保管する。	

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
1000 ml PE ボトル	UF/UA/Reserve		採水装置のフローラインから試料を直接採取し，容器を完全に満たす。試料の容器を別のビニル袋に入れ，必要になるまで冷蔵庫で保管する。	

採水手順書Ｉａ（主要成分の定常分析用試料）

- タンク中の掘削水を直接，PE ボトルに採取し，さらに，pH，酸化還元電位，電気伝導度，温度測定用に試料を分取する。
- 残試料については，追加分析が生じる可能性もあるため，ラベルを添付した PE ボトルに封入し，掘削に関する作業記録が確認され，作業が終了するまで保管する。

採水手順書Ⅱ（限定成分分析用試料）

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
PE:ポリエチレン	F: 濾過 UF:無濾過 UA:酸無添加	分析試料の容器にラベルを貼り付け，試薬を加えた後，分析試料をシリンジとフィルターとともにラベルを貼り付けたビニル袋に入れておく。		
大口径 200 ml PE ボトル（取水バルブ＋排気バルブ付）			採水装置のフローラインから試料を直接採取する。携帯ドラフトの中で 50 ml シリンジを用いて分析試料を採取し，容器の中に注入する。試料を分取する際，必要に応じて 0.45μm フィルター（ホルダーで固定）による濾過を行う。なお，濾液の最初の 5 ml は捨てる。異なる試料容器毎にフィルターとホルダーを交換する。	
50 ml PE ボトル	F/HNO_3/Cation	パスツール・ピペットを使って濃硝酸 2 滴を空の容器に加えておく。	濾過試料で両方の容器を完全に満たす。	陽イオン
30 ml PE ボトル	F/UA/Anion		濾過試料で容器を完全に満たす。	陰イオン
30 ml PE ボトル	F/UA/Alkalinity		濾過試料で容器を完全に満たす。	pH，アルカリ度
28 ml ガラス瓶	UF/UA/Stable O+H		無濾過の試料で容器を完全に満たす。	安定同位体
大口径 200 ml PE ボトル			採水装置のフローラインから再び試料を直接採取する。試料の pH，電気伝導度，温度を計測し，計測後，試料を廃棄する。	pH，電気伝導度，温度の現場計測
			ラベルを貼り付けたビニル袋に全ての分析試料の容器（保存試料は除外）を入れ，分析に供するまで冷蔵庫で保管する。	
1000 ml PE ボトル	UF/UA/Reserve		採水装置のフローラインから試料を直接採取し，容器を完全に満たす。試料の容器を別のビニル袋に入れ，必要になるまで冷蔵庫で保管する。	

採水手順書Ⅲ（全成分分析用試料）

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
PE:ポリエチレン	F: 濾過 UF:無濾過 UA:酸無添加	分析試料の容器にラベルを貼り付け，試薬を加えた後，分析試料をシリンジとフィルターとともにラベルを貼り付けたビニル袋に入れておく。		
大口径 200 ml PE ボトル（取水バルブ＋排気バルブ付）			採水装置のフローラインから試料を直接採取する。携帯ドラフトの中で 50 ml シリンジを用いて分析試料を採取し，容器の中に注入する。試料を分取する際，必要に応じて 0.45μm フィルター（ホルダーで固定）による濾過を行う。なお，濾液の最初の 5 ml は捨てる。異なる試料容器毎にフィルターとホルダーを交換する。	
50 ml PE ボトル	F/HNO_3/Cation	パスツール・ピペットを使って濃硝酸 2 滴を空の容器に加えておく。	濾過試料で両方の容器を完全に満たす。	陽イオン
30 ml PE ボトル	F/UA/Anion		濾過試料で容器を完全に満たす。	陰イオン
30 ml PE ボトル	F/UA/Alkalinity		濾過試料で容器を完全に満たす。	pH，アルカリ度，全無機炭素，全有機炭素
30 ml PE ボトル	UF/NaOH/Sulphide	水酸化ナトリウム 1 粒を空の容器に加えておく。	無濾過の試料で容器を完全に満たす。この際，発熱反応が生じる。	硫化物イオン
28 ml ガラス瓶	UF/UA/Stable O+H		無濾過の試料で容器を完全に満たす。	安定同位体
500 ml ガラス瓶	UF/UA/^{3}H		わずかに（25 ml 程度）気泡を残して，無濾過の試料で容器を満たす。	トリチウム
50 ml ガラス瓶	UF/UA/Noble gases		無濾過の試料で容器を完全に満たす。	希ガス

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
1000 ml 密封フラスコ	UF/UA/Gas	キャニスター自動洗浄装置を用いて容器内を真空にし，不活性ガスを充填する。これを 9 回繰り返して容器内を完全に真空・不活性の状態にする。	採水装置のフローラインから試料を直接採取する。	地上で地下水中に残存している溶存ガス
200 ml 密封フラスコ	UA/Redox	キャニスター自動洗浄装置を用いて容器内を真空にし，不活性ガスを充填する。これを 9 回繰り返して容器内を完全に真空・不活性の状態にする。	採水装置のフローラインから試料を直接採取する。試料は採取後 6 時間以内に分析する。	酸化還元パラメータ
大口径 1000 ml PE ボトル（取水バルブ＋排気バルブ付）			採水装置のフローラインから試料を直接採取する。携帯ドラフトの中で 50 ml シリンジを用いて分析試料を採取し，容器の中に注入する。試料を分取する際，必要に応じて 0.45μm フィルター（ホルダーで固定）による濾過を行う。なお，濾液の最初の 5 ml は捨てる。異なる試料容器毎にフィルターとホルダーを交換する。	
1000 ml ガラス瓶	F/NaOH/^{14}C	5N 水酸化ナトリウム溶液 10 ml を容器に添加する。	濾過試料で容器を完全に満たす。試料に 2N 塩化ストロンチウム溶液 10 ml を添加し，炭酸ストロンチウムを沈殿させる。	炭素 14
1000 ml PE ボトル	F/NaOH/^{34}S	5N 水酸化ナトリウム溶液 1 ml を容器に添加する。	濾過試料で容器を完全に満たす。試料に 1N 酢酸亜鉛溶液 1.5 ml を添加し，硫化亜鉛を沈殿させる。	硫黄 34
1000 ml ガラス瓶	F/UA/^{13}C			炭素 13
5000 ml PE ボトル	F/UA/^{36}Cl			塩素 36
20 L PE 容器	F/UA/U-series			ウラン系列核種

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
大口径 200 ml PE ボトル（取水バルブ＋排気バルブ付）			採水装置のフローラインから再び試料を直接採取する。試料の pH，電気伝導度，温度を計測し，計測後，試料を廃棄する。	pH，電気伝導度，温度の現場計測
			ラベルを貼り付けたビニル袋に全ての分析試料の容器（保存試料は除外）を入れ，分析に供するまで冷蔵庫で保管する。	
20 L PE ボトル	UF/UA/Reserve		採水装置のフローラインから試料を直接採取し，容器を完全に満たす。試料の容器を別のビニル袋に入れ，必要になるまで冷蔵庫で保管する。	

採水手順書Ⅳ（全成分分析およびコロイド・微生物調査用試料）

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
PE:ポリエチレン PP:ポリプロピレン	F: 濾過 UF:無濾過 UA:酸無添加	分析試料の容器にラベルを貼り付け，試薬を加えた後，分析試料をシリンジとフィルターとともにラベルを貼り付けたビニル袋に入れておく。		
密封容器（コロイド採取装置を採水装置のフローラインに接続）			フローライン上で試料を 0.45μm フィルター→0.20μm フィルターの順で濾過し，濾液を試料容器毎に取り分ける。なお，濾液の最初の 5 ml は捨てる。試料容器毎にフィルターを交換するか否かは，試料中に存在するコロイドの量に依存するため，これを必ず最初に確認する。	コロイド
50 ml PE ボトル	F/HNO_3/Cation	パスツール・ピペットを使って濃硝酸 2 滴を空の容器に加えておく。	濾過試料で両方の容器を完全に満たす。	陽イオン
30 ml PE ボトル	F/UA/Anion		濾過試料で容器を完全に満たす。	陰イオン
30 ml PE ボトル	F/UA/Alkalinity		濾過試料で容器を完全に満たす。	pH，アルカリ度，全無機炭素，全有機炭素
30 ml PE ボトル	UF/NaOH/Sulphide	水酸化ナトリウム 1 粒を空の容器に加えておく。	無濾過の試料で容器を完全に満たす。この際，発熱反応が生じる。	硫化物イオン
28 ml ガラス瓶	UF/UA/Stable O+H		無濾過の試料で容器を完全に満たす。	安定同位体
500 ml ガラス瓶	UF/UA/^{3}H		わずかに（25 ml 程度）気泡を残して，無濾過の試料で容器を満たす。	トリチウム
50 ml ガラス瓶	UF/UA/Noble gases		無濾過の試料で容器を完全に満たす。	希ガス

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
1000 ml 密封フラスコ	UF/UA/Gas	キャニスター自動洗浄装置を用いて容器内を真空にし，不活性ガスを充填する。これを 9 回繰り返して容器内を完全に真空・不活性の状態にする。	採水装置のフローラインから試料を直接採取する。	地上で地下水中に残存している溶存ガス
200 ml 密封フラスコ	UA/Redox	キャニスター自動洗浄装置を用いて容器内を真空にし，不活性ガスを充填する。これを 9 回繰り返して容器内を完全に真空・不活性の状態にする。	採水装置のフローラインから試料を直接採取する。試料は採取後 6 時間以内に分析する。	酸化還元パラメータ
大口径 1000 ml PE ボトル（取水バルブ＋排気バルブ付）			採水装置のフローラインから試料を直接採取する。携帯ドラフトの中で 50 ml シリンジを用いて分析試料を採取し，容器の中に注入する。試料を分取する際，必要に応じて 0.45μm フィルター（ホルダーで固定）による濾過を行う。なお，濾液の最初の 5 ml は捨てる。異なる試料容器毎にフィルターとホルダーを交換する。	
1000 ml ガラス瓶	F/NaOH/^{14}C	5N 水酸化ナトリウム溶液 10 ml を容器に添加する。	濾過試料で容器を完全に満たす。試料に 2N 塩化ストロンチウム溶液 10 ml を添加し，炭酸ストロンチウムを沈殿させる。	炭素 14
1000 ml PE ボトル	F/NaOH/^{34}S	5N 水酸化ナトリウム溶液 1 ml を容器に添加する。	濾過試料で容器を完全に満たす。試料に 1N 酢酸亜鉛溶液 1.5 ml を添加し，硫化亜鉛を沈殿させる。	硫黄 34
1000 ml ガラス瓶	F/UA/^{13}C			炭素 13
5000 ml PE ボトル	F/UA/^{36}Cl			塩素 36
20 L PE 容器	F/UA/U-series			ウラン系列核種
50 ml γ線滅菌済み PP ボトル	F/Formalin/M-TC		濾過試料を採取した直後に，終濃度が 4%になるように，試料に中性化ホルマリンを添加して細胞を固定する。試料は冷蔵庫で保管する。	全菌数

容器の種類	分類ラベル	室内での前処理	現場での作業手順	分析項目
1000 ml ガラス気密容器	UF/UA/M-activity	容器をオートクレーブで滅菌処理（121℃，15 分以上）し，容器内を 99.999%以上の高純度不活性ガスで充填する。	大気中の酸素が混入しないように，嫌気的な環境下で採水装置のフローラインから試料を直接採取する。採取試料は，脱酸素剤などと一緒に嫌気的に封入し，冷蔵庫で保管する。	微生物活性
2000 ml PP ボトル	UF/UA/M-DNA	容器をオートクレーブで滅菌処理（121℃，15 分以上）する。	採水装置のフローラインから試料を直接採取する。採取試料は直ちに 0.20μm フィルターで濾過し、捕集した微生物細胞をフィルターごと冷凍保存する。	微生物群集組成（DNA 解析）
大口径 200 ml PE ボトル			採水装置のフローラインから再び試料を直接採取する。試料の pH，電気伝導度，温度を計測し，計測後，試料を廃棄する。	pH，電気伝導度，温度の現場計測
			ラベルを貼り付けたビニル袋に全ての分析試料の容器（保存試料は除外）を入れ，分析に供するまで冷蔵庫で保管する。	
20 L PE ボトル	UF/UA/Reserve		採水装置のフローラインから試料を直接採取し，容器を完全に満たす。試料の容器を別のビニル袋に入れ，必要になるまで冷蔵庫で保管する。	

採水手順書Ⅴ（代替手法）

1) 洗浄済みの試料容器にラベルを貼り付けておく。
2) ポリエチレンの柄杓でタンク中の掘削水をすくい取る。
3) 試料容器を少量の掘削水で 3 回共洗いした後，試料容器を掘削水で満たす。
4) 現場の実験室で試料の簡易観察を実施する。チェック項目は，色，臭い，気泡，濁り，沈殿の有無である。
5) 現場の実験室で試料を分取した後，ただちに 0.45μm フィルターで濾過する。掘削水には試薬などの添加を行わない。
6) 試料容器のラベルに必要な情報を記入する。記入する項目は，ボーリング孔番号，試料番号，採水日時，採水深度，採水者名，簡易観察結果である。
7) 1 時間毎に採取した試料を除いて，全ての試料を化学分析に供するまで現場の実験室の冷蔵庫内で保管する。

採水の時期と頻度

- 掘削が始まる前に初期の掘削水を採取する。
- ボーリング孔の掘削中は，循環している掘削水を 1 時間毎，1 日毎，掘削長 100 mabh 毎に現場で採取する。24 時間連続掘削の場合，採水は夜間に行い，化学分析は日中に行う。
- 掘削水を補給するために地下水や河川水などを用いて掘削水を新たに作成する場合は，使用する水についても採水・分析し，保管する。

採水・取り扱い場所

- タンク脇での採水
- 現場の実験室での試料の前処理と保管

採水量

- 以下の掘削水（掘削に使用する水を含む）試料を採取する。
  a) 100 ml：1 時間毎に採取，トレーサー濃度測定用
  b) 100 ml：1 日毎に採取，保管用（ポリエチレンボトル）
  c) 1000 ml：1 日毎に採取，主成分分析用
  d) 1000 ml：掘削長 100 mabh 毎に採取，安定同位体分析用
  e) 20 L：掘削長 100 mabh 毎に採取，保管用（ポリエチレンタンク）

コア採取手順書Ⅰ

コアの取り扱いは，迅速さに重点を置いて，数段階の単純な作業で行う。全体の作業はコアの回収からワックスによる密封まで 10 分以内で終了させる。いかなる作業の遅延も漏れなくボーリング調査記録に必ず記す。迅速性の観点から，現場において標準的に行われるコアの記載と写真撮影の作業は，実験室のグローブボックス内で行うことを検討する。

1) コアの回収後，直ちにコアの表面を拭いて乾かし，速やかに写真撮影を行う。
2) 岩石カッター，パワーチゼル，空冷コアラーなどを使用して，コアの外側 15 mm 程度をトリミングする（以前は 10 mm；Charlton ほか[4] 参照）。
3) 乾いた布で水分をきれいに拭きとる。
4) アルミパウチ袋（あるいはアルミ蒸着袋）にコアを入れ，袋が試料に密着する状態になるまで小さな電動ポンプで空気を吸い出す。袋の口元を加熱シーラーで熱融着する。
5) もう一度繰り返す。
6) コア試料にアルミホイルをきつく巻きつける。
7) コア試料を溶融したワックスに浸け完全に密封する（写真 1 参照）。
8) コア試料を実験室へ運び，間隙水の抽出は 3 日以内に実施する。

写真 1　コアはアルミパウチ袋とアルミホイルの 2 層で封入した後，間隙水の抽出までワックスで密封する（太田ほか[5] 参照）

References/参考文献

1) Kunimaru, T., Ota, K., Yamamoto, H. and Alexander, W.R. (2010): Groundwater/Porewater Hydrochemistry at Horonobe URL: Data Freeze I – Preliminary Data Quality Evaluation for Boreholes HDB-9, 10 and 11. JAEA-Research 2010-035, JAEA, Tokai, Japan.
2) Pitkänen, P., Ahokas, H., Ylä-Mella, M., Partamies, S., Snellman, M. and Hellä, P. (Eds.) (2007): Quality Review of Hydrochemical Baseline Data from the Olkiluoto Site. Posiva 2007-05, Posiva, Olkiluoto, Finland.
3) Smellie, J.A.T., Tullborg, E-L. et al. (2008): Explorative Analysis of Major Components and Isotopes. SDM–Site Forsmark. SKB Report R-08-84, SKB, Stockholm, Sweden.
4) Charlton, B.D., Milodowski, A.E., Cave, M.R., Entwistle, D.C. and Darling, W.G. (2005): Specialist Pore-Water Characterisation in the Horonobe Boreholes HDB-9, HDB-10 and HDB-11: Final Report. BGS CR 05-147, BGS, Keyworth, UK.
5) Ota, K., Abe, H. and Kunimaru, T. (Eds.) (2010): Horonobe Underground Research Laboratory Project, Synthesis of Phase I Investigations 2001–2005, Volume “Geoscientific Research”. JAEA-Research 2010-068, JAEA, Tokai, Japan.

Appendix 3:

Examples of common groundwater colloid separation methods[1)]

Method	Short description	Advantages and disadvantages
Ultracentrifugal deposition[2)]	Colloids deposited from a dispersion onto a carbon-coated copper grid using an ultracentrifuge. Particles above a certain minimum size (which is dependent on the centrifugal field, height of solution and duration of centrifugation) from a known volume of solution are deposited, essentially quantitatively, onto the activated top surface of the grid. In general, centrifugation conditions are selected so that all particles greater than about 15 nm are sedimented onto the carbon film.	Formation of salt particles from the original leachate solution on drying grid. Can be minimised by washing grids *in situ* in the centrifuge tubes using dilute electrolyte solution. Significant likelihood of colloid agglomeration (into larger particles) noted[3)]. Can be used on-site[4)], but requires sample handling which may perturb the original *in situ* conditions.
Direct filtration[5)] Filters can be coupled in series (in decreasing nominal pore size) or in parallel (also known as 'inert filtration')[4)]	Directly filter solution through appropriate nominal pore size filters held in a range of different filter holders. The water is collected in a standard 50 mL (for example) capacity filtration cell, first being passed through a 1 μm nominal pore size pre-filter (to remove any large particles). The cell can be evacuated either by the application of a vacuum to the cell or by gas overpressure.	Easy to set up as a closed system in the field[6)]. Repeated filter handling can easily cause sample contamination. In addition, the operator has to have enough experience to know when enough water has been filtered or a thick 'cake' of colloids can be produced, making examining individual colloid morphology, for example, difficult. Inert filtration avoids the build up of 'cake'.
Field Flow Fractionation (FFF)[7)] Asymmetric Flow FFF (or AF4 as it is most commonly known) is being developed as the most promising of a whole range of FFF methods as it can separate (bio-) polymers, particles and colloids in the size range of 1 nm to 100 μm.	Separation occurs in a thin flow channel comparable to the separation column used in chromatography. Flow in the channel is laminar and a force is generated perpendicular to the flow – in AF4, this is a liquid cross flow. Colloids are separated in the laminar flow by the velocity gradient and are forced toward the lower membrane by the cross flow. The cross flow passes through the membrane while the colloids are bounced back into the laminar flow. Smaller colloids diffuse back into the channel further on and are caught in the faster parts of the laminar flow and so are eluted more rapidly than larger colloids.	Potential reaction of the colloids in the cross flow field. Not easily portable for well head and other site use. Many analytical methods can be effectively directly coupled to the sample stream[8)], so minimising potential sampling artefacts.

地下水コロイドの捕集方法の例 [1)]

方　法	概　要	長所・短所
超遠心沈殿法 [2)]	超遠心分離によって，分散しているコロイドを炭素被覆した銅の孔格子上に沈殿させる。ある最小のサイズ（遠心力場，溶解度，遠心分離の時間に依存）よりも大きなコロイドは，一定量の溶液から格子の活性表面上に基本的には定量的に沈殿する。一般には，約 15 nm 以上のサイズのコロイドが炭素被覆上に全て沈殿するように，遠心分離の条件を設定する。	・乾燥した孔格子上に，浸出原液から塩粒子が形成されるが，希薄な電解質溶液を用いて遠心分離管中で格子を洗浄することによってそれを低減できる。 ・コロイドが凝集し大きな粒子になる可能性が極めて大きい [3)]。 ・現場での適用 [4)] が可能であるものの，必要とされる試料の取り扱いによって，試料が元来有する状態を乱す可能性がある。
直接濾過法 [5)] フィルターを，公称孔径が小さくなるように直列に，あるいは並列に組み合わせる方法である（これは，不活性濾過法 [4)] として知られている）。	目的に応じて選定した異なる公称孔径のフィルターをホルダーに取り付け，試料を直接濾過する。試料は標準的な容量（例えば，50 ml）の濾過セルに集め，最初に公称孔径 1μm のフィルターを通過させて大きな粒子を取り除く。この際，濾過セル内の溶液は，真空引きもしくはガスによる加圧によって排出する。	・現場において濾過システム（閉鎖系）の準備が容易である [6)]。 ・フィルターの繰り返し使用による試料の汚染が生じやすい。 ・作業者は，十分な量の試料を濾過した，あるいはコロイドの固まりが形成された（それにより，例えば，コロイドの形態に関する調査を困難にしてしまった）ことを把握できる十分な経験を有していなければならない。なお，不活性濾過法は，コロイドの固まりの形成を防ぐことが可能である。
フィールドフローフラクショネーション（FFF）法 [7)] 非対称フローFFF 法（AF4 法として広く知られている）は，1 nm～100μm サイズの高分子，粒子，コロイドを分離できる全ての FFF 法の中で，最も有効な方法として開発されている。	クロマトグラフィー用の分離カラムと同程度の間隔の狭いフローチャンネル内で分離を行う。フローチャンネル内の層流に対して，垂直な力の場を加えて交差流を発生させることにより，コロイドは層流中の速度勾配によって分離され，交差流によってフローチャンネル下部のメンブレンフィルターに向かって移動する。さらに，コロイドが反跳して層流中に戻る間に，交差流はメンブランフィルターを通過する。したがって，小さなコロイドは層流中により深く拡散し，速い流れに捕捉されるために，大きなコロイドよりも速く溶出する。	・試料の流れに対して様々な分析手法を効果的に直結することができ [8)]，試料のサンプリングに伴う汚染などの影響を低減することができる。 ・交差流が生じる場におけるコロイドの反応が想定される。 ・孔口や調査現場において使用する際の持ち運びが困難である。

References/参考文献

1) Alexander, W.R., Berry, J.A., Kelly, M.J. and Swanton, S. (2011): Review of Colloids in the Geosphere and their Treatment in Performance Assessment, Report to NDA-RWMD, Serco/TAS/002924/01, Serco, Didcot, UK.

2) Zänker, H., Hüttig, G., Moll, H. and Nitsche, H. (1997): Comparison of Methods for Colloid Particle Sizing: Filtration, Centrifugation, Photon Correlation Spectroscopy (PCS), and Scanning Electron Microscopy (SEM), Report FZR-280, Annual Report 1996 of Institute of Radiochemistry, Forschungszentrum Rossendorf, Germany.

3) Kearl, P.M., Korste, N.E. and Cronk, T.A. (1992): Suggested modifications to ground water sampling procedures based on observations from the colloidal borescope, Ground Water Monitoring Review, 12, pp.155–161.

4) Laaksoharju, M., Vuorinen, U., Snellman, M., Allard, B., Pettersson, C., Helenius, J. and Hinkkanen, H. (1993): Colloids or Artefacts? A TVO/SKB Cooperation Project in Olkiluoto, Finland, SKB TR-93-32, SKB, Stockholm, Sweden.

5) McCarthy, J. and Degueldre, C. (1993): Sampling and characterisation of colloids in ground-water for studying their role in contaminant transport. In: Environmental Particles, vol.2, J.Buffle and H. van Leeuwn, Lewis Publishers.

6) Wetton, P.D., Pearce, J.M., Alexander, W.R., Milodowski, A.E., Reeder, S., Wragg, J. and Salameh, E. (1998): The production of colloids at the cement/host rock interface, Chapter 10 in Smellie, J.A.T. (Ed.), Maqarin Natural Analogue Study: Phase III. SKB Report TR-98-04, SKB, Stockholm, Sweden.

7) Balousha, M., Kammer, F.V., Motelica-Heino, M., Hilal, H.S. and Le Coustumer, P. (2006): Size fractionation and characterization of natural colloids by flow-field flow fractionation coupled to multi-angle laser light scattering, Journal of Chromatography A, 1104, pp.272–281.

8) Lead, J.R. and Wilkinson, K. (2006): Aquatic colloids and nanoparticles: Current knowledge and future trends, Environmental Chemistry, 3, pp.159–171.

国際単位系（SI）

表１．SI 基本単位

基本量	SI 基本単位	
	名称	記号
長さ	メートル	m
質量	キログラム	kg
時間	秒	s
電流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光度	カンデラ	cd

表２．基本単位を用いて表されるSI組立単位の例

組立量	SI 基本単位	
	名称	記号
面積	平方メートル	m^2
体積	立法メートル	m^3
速さ，速度	メートル毎秒	m/s
加速度	メートル毎秒毎秒	m/s^2
波数	毎メートル	m^{-1}
密度，質量密度	キログラム毎立方メートル	kg/m^3
面積密度	キログラム毎平方メートル	kg/m^2
比体積	立方メートル毎キログラム	m^3/kg
電流密度	アンペア毎平方メートル	A/m^2
磁界の強さ	アンペア毎メートル	A/m
量濃度(a)，濃度	モル毎立方メートル	mol/m^3
質量濃度	キログラム毎立法メートル	kg/m^3
輝度	カンデラ毎平方メートル	cd/m^2
屈折率(b)	（数字の） 1	1
比透磁率(b)	（数字の） 1	1

(a) 量濃度（amount concentration）は臨床化学の分野では物質濃度（substance concentration）ともよばれる。
(b) これらは無次元量あるいは次元１をもつ量であるが、そのことを表す単位記号である数字の１は通常は表記しない。

表３．固有の名称と記号で表されるSI組立単位

組立量	SI 組立単位			
	名称	記号	他のSI単位による表し方	SI基本単位による表し方
平面角	ラジアン(b)	rad	1 (b)	m/m
立体角	ステラジアン(b)	sr(c)	1 (b)	m^2/m^2
周波数	ヘルツ(d)	Hz		s^{-1}
力	ニュートン	N		m kg s^{-2}
圧力，応力	パスカル	Pa	N/m^2	m^{-1} kg s^{-2}
エネルギー，仕事，熱量	ジュール	J	N m	m^2 kg s^{-2}
仕事率，工率，放射束	ワット	W	J/s	m^2 kg s^{-3}
電荷，電気量	クーロン	C		s A
電位差（電圧），起電力	ボルト	V	W/A	m^2 kg s^{-3} A^{-1}
静電容量	ファラド	F	C/V	m^{-2} kg^{-1} s^4 A^2
電気抵抗	オーム	Ω	V/A	m^2 kg s^{-3} A^{-2}
コンダクタンス	ジーメンス	S	A/V	m^{-2} kg^{-1} s^3 A^2
磁束	ウエーバ	Wb	Vs	m^2 kg s^{-2} A^{-1}
磁束密度	テスラ	T	Wb/m^2	kg s^{-2} A^{-1}
インダクタンス	ヘンリー	H	Wb/A	m^2 kg s^{-2} A^{-2}
セルシウス温度	セルシウス度(e)	℃		K
光束	ルーメン	lm	cd sr(c)	cd
照度	ルクス	lx	lm/m^2	m^{-2} cd
放射性核種の放射能(f)	ベクレル(d)	Bq		s^{-1}
吸収線量, 比エネルギー分与, カーマ	グレイ	Gy	J/kg	m^2 s^{-2}
線量当量, 周辺線量当量, 方向性線量当量, 個人線量当量	シーベルト(g)	Sv	J/kg	m^2 s^{-2}
酸素活性	カタール	kat		s^{-1} mol

(a)SI接頭語は固有の名称と記号を持つ組立単位と組み合わせても使用できる。しかし接頭語を付した単位はもはやコヒーレントではない。
(b)ラジアンとステラジアンは数字の１に対する単位の特別な名称で、量についての情報をつたえるために使われる。実際には、使用する時には記号radおよびsrが用いられるが、習慣として組立単位としての記号である数字の１は明示されない。
(c)測光学ではステラジアンという名称と記号srを単位の表し方の中に、そのまま維持している。
(d)ヘルツは周期現象についてのみ、ベクレルは放射性核種の統計的過程についてのみ使用される。
(e)セルシウス度はケルビンの特別な名称で、セルシウス温度を表すために使用される。セルシウス度とケルビンの単位の大きさは同一である。したがって、温度差や温度間隔を表す数値はどちらの単位で表しても同じである。
(f)放射性核種の放射能（activity referred to a radionuclide）は、しばしば誤った用語で"radioactivity"と記される。
(g)単位シーベルト（PV,2002,70,205）についてはCIPM勧告2（CI-2002）を参照。

表４．単位の中に固有の名称と記号を含むSI組立単位の例

組立量	SI 組立単位		
	名称	記号	SI 基本単位による表し方
粘度	パスカル秒	Pa s	m^{-1} kg s^{-1}
力のモーメント	ニュートンメートル	N m	m^2 kg s^{-2}
表面張力	ニュートン毎メートル	N/m	kg s^{-2}
角速度	ラジアン毎秒	rad/s	m m^{-1} s^{-1}=s^{-1}
角加速度	ラジアン毎秒毎秒	rad/s^2	m m^{-1} s^{-2}=s^{-2}
熱流密度，放射照度	ワット毎平方メートル	W/m^2	kg s^{-3}
熱容量，エントロピー	ジュール毎ケルビン	J/K	m^2 kg s^{-2} K^{-1}
比熱容量，比エントロピー	ジュール毎キログラム毎ケルビン	J/(kg K)	m^2 s^{-2} K^{-1}
比エネルギー	ジュール毎キログラム	J/kg	m^2 s^{-2}
熱伝導率	ワット毎メートル毎ケルビン	W/(m K)	m kg s^{-3} K^{-1}
体積エネルギー	ジュール毎立方メートル	J/m^3	m^{-1} kg s^{-2}
電界の強さ	ボルト毎メートル	V/m	m kg s^{-3} A^{-1}
電荷密度	クーロン毎立方メートル	C/m^3	m^{-3} sA
表面電荷	クーロン毎平方メートル	C/m^2	m^{-2} sA
電束密度，電気変位	クーロン毎平方メートル	C/m^2	m^{-2} sA
誘電率	ファラド毎メートル	F/m	m^{-3} kg^{-1} s^4 A^2
透磁率	ヘンリー毎メートル	H/m	m kg s^{-2} A^{-2}
モルエネルギー	ジュール毎モル	J/mol	m^2 kg s^{-2} mol^{-1}
モルエントロピー, モル熱容量	ジュール毎モル毎ケルビン	J/(mol K)	m^2 kg s^{-2} K^{-1} mol^{-1}
照射線量（X線及びγ線）	クーロン毎キログラム	C/kg	kg^{-1} sA
吸収線量率	グレイ毎秒	Gy/s	m^2 s^{-3}
放射強度	ワット毎ステラジアン	W/sr	m^4 m^{-2} kg s^{-3}=m^2 kg s^{-3}
放射輝度	ワット毎平方メートル毎ステラジアン	$W/(m^2$ sr)	m^2 m^{-2} kg s^{-3}=kg s^{-3}
酵素活性濃度	カタール毎立方メートル	kat/m^3	m^{-3} s^{-1} mol

表５．SI 接頭語

乗数	接頭語	記号	乗数	接頭語	記号
10^{24}	ヨタ	Y	10^{-1}	デシ	d
10^{21}	ゼタ	Z	10^{-2}	センチ	c
10^{18}	エクサ	E	10^{-3}	ミリ	m
10^{15}	ペタ	P	10^{-6}	マイクロ	μ
10^{12}	テラ	T	10^{-9}	ナノ	n
10^9	ギガ	G	10^{-12}	ピコ	p
10^6	メガ	M	10^{-15}	フェムト	f
10^3	キロ	k	10^{-18}	アト	a
10^2	ヘクト	h	10^{-21}	ゼプト	z
10^1	デカ	da	10^{-24}	ヨクト	y

表６．SIに属さないが、SIと併用される単位

名称	記号	SI 単位による値
分	min	1 min=60s
時	h	1h =60 min=3600 s
日	d	1 d=24 h=86 400 s
度	°	1°=(π/180) rad
分	’	1’=(1/60)°=(π/10800) rad
秒	”	1”=(1/60)’=(π/648000) rad
ヘクタール	ha	$1ha=1hm^2=10^4m^2$
リットル	L, l	$1L=11=1dm^3=10^3cm^3=10^{-3}m^3$
トン	t	$1t=10^3$ kg

表７．SIに属さないが、SIと併用される単位で、SI単位で表される数値が実験的に得られるもの

名称	記号	SI 単位で表される数値
電子ボルト	eV	$1eV=1.602\ 176\ 53(14)\times10^{-19}J$
ダルトン	Da	$1Da=1.660\ 538\ 86(28)\times10^{-27}kg$
統一原子質量単位	u	1u=1 Da
天文単位	ua	$1ua=1.495\ 978\ 706\ 91(6)\times10^{11}m$

表８．SIに属さないが、SIと併用されるその他の単位

名称	記号	SI 単位で表される数値
バール	bar	1 bar=0.1MPa=100kPa=10^5Pa
水銀柱ミリメートル	mmHg	1mmHg=133.322Pa
オングストローム	Å	1 Å=0.1nm=100pm=10^{-10}m
海里	M	1 M=1852m
バーン	b	$1\ b=100fm^2=(10^{-12}cm)2=10^{-28}m^2$
ノット	kn	1 kn=(1852/3600)m/s
ネーパ	Np	SI単位との数値的な関係は、対数量の定義に依存。
ベル	B	
デジベル	dB	

表９．固有の名称をもつCGS組立単位

名称	記号	SI 単位で表される数値
エルグ	erg	$1\ erg=10^{-7}$ J
ダイン	dyn	$1\ dyn=10^{-5}$N
ポアズ	P	1 P=1 dyn s cm^{-2}=0.1Pa s
ストークス	St	1 St =$1cm^2$ s^{-1}=$10^{-4}m^2$ s^{-1}
スチルブ	sb	1 sb =1cd cm^{-2}=10^4cd m^{-2}
フォト	ph	1 ph=1cd sr cm^{-2} 10^4lx
ガル	Gal	1 Gal =1cm s^{-2}=$10^{-2}ms^{-2}$
マクスウェル	Mx	1 Mx = 1G cm^2=10^{-8}Wb
ガウス	G	1 G =1Mx cm^{-2} =10^{-4}T
エルステッド(c)	Oe	1 Oe≙ $(10^3/4\pi)$A m^{-1}

(c) ３元系のCGS単位系とSIでは直接比較できないため、等号「 ≙ 」は対応関係を示すものである。

表10．SIに属さないその他の単位の例

名称	記号	SI 単位で表される数値
キュリー	Ci	$1\ Ci=3.7\times10^{10}Bq$
レントゲン	R	$1\ R = 2.58\times10^{-4}C/kg$
ラド	rad	$1\ rad=1cGy=10^{-2}Gy$
レム	rem	$1\ rem=1\ cSv=10^{-2}Sv$
ガンマ	γ	1γ=1 nT=10-9T
フェルミ		1フェルミ=1 fm=10-15m
メートル系カラット		1メートル系カラット = 200 mg = 2×10-4kg
トル	Torr	1 Torr = (101 325/760) Pa
標準大気圧	atm	1 atm = 101 325 Pa
カロリー	cal	1cal=4.1858J（「15℃」カロリー），4.1868J（「IT」カロリー）4.184J（「熱化学」カロリー）
ミクロン	μ	1 μ =1μm=10^{-6}m

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