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The SKB Spent Fuel Corrosion Programme

An evaluation of results from the experimental programme performed in the Studsvik Hot Cell Laboratory

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December 1997

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THE SKB SPENT FUEL CORROSION PROGRAMME

AN EVALUATION OF RESULTS FROM THE EXPERIMENTAL PROGRAMME PERFORMED IN THE STUDSVIK HOT CELL LABORATORY

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This report concerns a study which was conducted for SKB. The conclusions and viewpoints presented in the report are those of the author(s) and do not necessarily coincide with those of the client.

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FOREWORD

After a six month period for planning and fuel characterisation, the SKB experimental programme for the study of the corrosion of spent nuclear fuel was started in February 1982 at the Studsvik Hot Cell Laboratory. Since that time, the results obtained from individual tests and from the programme as a whole, have been published regularly as SKB and Studsvik technical reports and as articles in scientific journals.

This report presents a new and complementary evaluation of the analytical results from some of the fuel corrosion tests included in the programme, and is occasioned by the availability of the more extensive analytical data base provided by the commissioning for the analysis of radioactive specimens of an Inductively Coupled Plasma - Mass Spectrometry (ICP-MS) instrument at the Studsvik laboratory in1992.

Most of the corrosion tests included in the evaluation are still in progress, and it is hoped that the report will be helpful both for the design of more specifically-directed corrosion experiments with these fuel specimens, and for the selection of specimens for post-corrosion destructive examination.

ABSTRACT

During the last few years, many of the specimens in the SKB programme on the corrosion of spent fuel have been analysed by the ICP-MS technique, shortly after conclusion of the corrosion tests, or by the analysis of archive samples. Together with the previous results, this has made available a much more extended analytical data base than that available before, and this has been used in a new evaluation which complements those published earlier.

Some of the new analytical data is for tests performed on fuel specimens (from two reference fuel rods, one BWR and one PWR) which have been corrosion tested for over ten years. Most of the data refers to 16 fuel/clad specimens from a short BWR fuel rod, which had burnups over a range of 27.0 to 48.8 MWd/kg U. Detailed examination and characterisation of three other fuel specimens from the rod had shown that the specimens with the higher burnups in this series would have a fuel microstructure and alpha activity content and distribution which, theoretically, may promote enhanced corrosion. These specimens had been exposed to over 5 years of corrosion during nine water contact periods. The corrodants used were a simulated bicarbonate groundwater and deionised water, and both oxic and nominally anoxic conditions were included in the test matrix.

Most of the emphasis in the evaluation has, therefore, been on the possible effects on corrosion behaviour of the linear heat rating and burnup of the fuels. However, examination of the variation with water contact time of the fractional release rates of selected fission products and their total release over the five years of corrosion, have shown that the corrosion rates during the first few weeks of corrosion of the specimens with the higher burnups were lower than those for specimens with slightly lower burnup. Later, the corrosion rates converged for all specimens. This has been interpreted to be due to burnup-related differences in the fuel microstructure, particularly in the inter-connecting network of porosity and grain boundaries rather than at the pellet rim. This is discussed in detail in the report which also estimates the dissolution rates, normalised for surface area, for fuel/clad specimens and fuel fragments.

SAMMANFATTNING

Under de senaste åren har proverna från SKB;s bränslekorrosionsprogram analyserats med ICP-MS teknik kort efter att korrosionstesterna avslutats. Analyser av arkivprover från tidigare experiment har också genomförts. Tillsammans med tidigare resultat har detta gjort det möjligt att sammanställa en mycket mer utvidgad analysdatabas än den tidigare tillgängliga och detta har använts i en ny utvärdering, som kompletterar de som publicerats tidigare.

Några av dessa nya analysdata kommer från experiment med provbitar av bränsle (från två referensstavar, en BWR och en PWR), som har korrosionsprovats i över tio år. Huvuddelen data kommer från 16 bränsle/kapslingsprover från en kort BWR stav, som hade en utbränning i området 27.0 till 48.8 MWd/kg U. Detaljerad undersökning och karakterisering av tre andra provbitar från staven visade att proverna med hög utbränning i den här serien hade en bränslestruktur, som teoretiskt borde gynna ökade korrosion. Dessa prover hade exponerats för mer än fem års korrosion under nio vattenkontaktperioder. De korrodanter som användes var ett simulerad bikarbonat grundvatten och avjonat vatten och både oxiderande och nominellt anoxiska förhållanden ingick i test matrisen.

Mycket av tonvikten i utvärderingen har därför lagts på de möjliga effekterna av linjär effekttäthet och utbränning på korrosionen. Undersökningar av variationen av frigörelsehastigheterna med vattenkontakttid av utvalda fissionsprodukter och deras totala frigörelse under fem års korrosion visade emellertid att korrosionshastigheterna under de första veckorna var lägre för prover med hög utbränning än för prover med något lägre utbränning. Senare kom korrosionshastigheterna att sammanfalla för all prover. Detta har tolkats som vara orsakat av utbränningsrelaterade skillnader i bränslets mikrostruktur, särskilt skillnader i det sammanlänkade nätverk av porositet och korngränser snarare än skillnader i bränslekutsarnas periferi. Detta diskuteras i detalj i rapporten, som också innehåller uppskattningar av upplösningshastigheter, normaliserat till bränslearea, för bränsle/kapslings prover och bränslefragment.

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SUMMARY AND CONCLUSIONS

The report presents an evaluation of the results of the corrosion tests in the SKB Spent fuel corrosion programme which complements the evaluations published earlier. The new evaluation is based on an extended analytical data base consisting of results obtained by both the conventional analytical methods used earlier in the programme and by the direct analysis of sample solutions by the ICP-MS technique, which also provided data on other fission products (Rb, Ba, Mo and some rare-earths) and neptunium not measured previously.

By means of the retroactive ICP-MS analysis of archive solutions from the first five contact periods, detailed corrosion test results for the first nine contact periods (a total of five years of corrosion) of the Series 11 corrosion tests are available according to the extended analytical programme. Results from other corrosion tests with different fuels in the SKB programme are included in the evaluation for comparison purposes.

The data base is presented in an appendix as tabulations of release fractions for selected actinides and fission products for the three sampling fractions in each corrosion test, viz. Centrifugate, membrane filter and vessel strip solution. In another appendix, the centrifugate results for selected actinide and rare earth elements are also tabulated as molarities.

The 16 fuel/clad segments in the Series 11 corrosion tests were all from the same BWR fuel rod but had different burnups (27.0 to 48.8 MWd/kg U) and, therefore, different linear heat ratings. A detailed post-irradiation examination programme had been performed on three fuel specimens with burnups of 21.2, 36.7 and 49.0 MWd/kg U from the same rod. Based on the results of these examinations, the successive development of the fuel microstructure typical of the so-called pellet rim effect was expected in the fuel corrosion specimens at the higher end of this range of burnups, and the steep build-up of alpha activity at the pellet rim as a function of burnup could be calculated. The experiment was designed, therefore, to study the possible effects on fuel corrosion behaviour of linear heat rating (thermal migration effects) and of burnup at levels where high porosity and high alpha activity were coincident at the pellet rim and, therefore, represented an enhanced potential for fuel corrosion due to the effects of alpha radiolysis at the fuel/water interface.

The effect of linear heat rating on the initial large release of cesium to the corrodant, due to its migration during irradiation, is well known, and was confirmed again in these experiments. A similar but smaller effect for Rb-85 and Rb-87 was demonstrated at these levels of heat rating. The results for the former isotope also indicated that the initial release was partly due to the

solubilisation of Rb-85 which had been formed by the decay of Kr-85 in the fuel rod void and deposited on the fuel and clad surfaces.

The release behaviours of cesium and rubidium, and in particular of molybdenum and technetium, in the Series 11 corrosion tests were also shown to be dependent on burnup, but not with a linear relationship. The effects were most pronounced during the first periods of water contact, but later, the release rates for a given nuclide for samples of different burnup tended to converge and then stabilise, and the release rates for different fission product nuclides also showed a tendency to converge. The cumulated release fractions for cesium and rubidium over the 5.09 year corrosion period first showed an increase with increased burnup, but decreased in fuel specimens with a bulk burnup exceeding about 45 MWd/kg U. For molybdenum and technetium the threshold for the decrease was at about 40 MWD/kg U.

These observations have been interpreted as being due to changes in the fuel microstructure at these higher burnups which affect the access of the water corrodant to the inter-connected network of micro-cracks and grain boundaries. Water ingress and fuel corrosion are successively further impeded due to the deposition of uranium from solution in this network, together with actinides and lanthanides, and probably some components from the bicarbonate groundwater.

The fractional release rates of strontium were used as quantitative monitors of the rate of matrix corrosion. The rates for the fuel/clad segment specimens in the Series 3 and 7 corrosion tests were in fairly good agreement with those for the Series 11 fuel specimens with similar burnups. For fuel/clad segments, after about 3 years of corrosion, the rates were almost constant with time in tests performed in simulated bicarbonate groundwater under oxic conditions. The effective fuel surface area which is exposed to corrosion at this stage in the corrosion process has been assumed to be mainly the fuel exposed freely to the corrodant at the two open ends of the segment. Otherwise, the fuel fragment surface area has been estimated by assuming the fuel to be in the form of cubes. In both cases, an arbitrary roughness factor of three has been applied. Using this methodology, the calculated dissolution rates for segment and fragment fuel specimens, normalised by the estimated surface areas, have shown good internal consistency in the SKB programme, and bracket the values obtained in other programmes.

1 INTRODUCTION

The first experiments in the current SKB programme for the study of the corrosion of spent nuclear fuel were started in the Hot Cell Laboratory of Studsvik Nuclear AB in February 1982. The spent fuel used in the first experiments (the Series 3 tests), were all from the same fuel rod from the Oskarshamn 1 BWR, (denoted O1-418-A6), which had been subjected to Post Irradiation Examination (PIE) at the laboratory, and, therefore, was readily available as source material for the corrosion tests. The burnup of the fuel, 42.0 MWd/kg U, was significantly higher than the average discharge burnup of BWR fuel at that time, (about 28 MWd/kg U), and was regarded as a clear advantage during the rod selection process.

Since spent nuclear fuel is a heterogeneous material, with a marked radial variation in the pellets of both microstructure and composition, (fission product and actinide concentrations), and adjacent pellets in the rod show different cracking patterns, it was decided that the corrosion tests should be performed on a relatively large number of specimens in order to obtain a reasonable statistical basis for evaluation of the test results. Other decisions with regard to experiment design for these early standardised tests, were to use sections of fuel with adherent Zircaloy clad as test specimens, and to perform each corrosion experiment as a series of sequential exposures to static corrodant solution. The complete cross-sections of fuel in the fuel/clad segments ensured that the radial variations in fuel properties mentioned above were taken into account, and the presence of the clad restricted access of the corrodant to the fuel surfaces, giving a relatively close simulation of repository conditions, assuming ingress of groundwater after breaching of both the waste canister and the fuel rod clad.

In the dilute, usually high pH corrodant solutions used in the corrosion tests, it was expected that the formation of colloids, particularly of the actinide elements, would be probable. Therefore, at the conclusion of each contact period between fuel and corrodant, aliquots of corrodant were centrifuged through membrane cone filters (Amicon Corp.) of type CT25, which have a >95% retention for molecules of molecular weight larger than 25 000. Further, after removal of corrodant solution, the corrosion test vessel, (usually a 250 ml Pyrex flask), was subjected to a desorption process using 5M HNO_3/0.5M HF for about 5 days in order to remove possible adsorbed or precipitated species from the vessel wall. Thus, for each contact period, three samples were obtained, defined in this report as centrifugate, membrane filter and vessel strip solution respectively.

Clearly, with a large number of individual fuel corrosion tests, each sampled at predetermined intervals, and with three fractions to be analysed after each contact period, the analytical workload was expected to be large, and the analytical programme was designed with this partly in mind.

Directly after centrifugation, the pH and carbonate concentration in the centrifugate were measured. All sample fractions were examined non-destructively by gamma spectrometry, (Cs-134, Cs-137, Ru-106, Ce-144 and Eu-154) following which, after acid-leaching of the membrane filter samples, analyses were performed for uranium, Sr-90 and Tc-99. Alpha spectrometric analysis was carried out without prior chemical separation on small sample aliquots, and counting rates from the alpha energy peaks at 5.15, 5.50, 5.82 and 6.12 MeV were measured. The peaks at 5.15 and 5.50 MeV each represented alpha particle energies from two nuclides, Pu-239 and Pu-240, and Pu-238 and Am-241 respectively. The peaks at 5.82 and 6.12 MeV represented Cm-244 and Cm-242 respectively.

This is only a short listing of the analyses applied, but it shows clearly the rather limited breadth of the analytical programme. A more detailed description of the standard experimental procedures and analytical methods used has been reported earlier. /1-1/ Similar types of rather limited analytical programmes have been used in most of the laboratories in other countries which have research programmes directed to the study of spent fuel corrosion.

Since fuel corrosion is generally considered to consist of three chronologically overlapping processes - the rapid dissolution of water-soluble fission products which had been released to fuel fragment and clad surfaces during irradiation, selective attack at grain boundaries giving enhanced release of species enriched there by diffusion processes during irradiation, and fuel matrix dissolution - much experimental effort has been directed internationally to distinguish between, and to quantify, these processes as functions of fuel properties and corrodant parameters. In such studies, it would be useful if a nuclide could be identified for use as a monitor of the fuel matrix dissolution/conversion process, i.e. a nuclide which is homogeneously dispersed as solid solution in the UO_2 matrix, and which is readily soluble in the relevant corrodant solutions. The measured concentrations of uranium itself, together with those of the lanthanides and actinides, in most corrosion tests cannot be used because of solubility limits, and, therefore, there has been much discussion in the literature and elsewhere, on the possibility of using fission product strontium as such a monitor. (The diffusion of fission product cesium to grain boundaries, and its release from, and reaction with, the fuel matrix during reactor irradiation is already well documented, as is the behaviour of technetium, which is found in fuel in small metallic particles together with Mo, Ru, Rh and Pd.)

With the limited analytical programme described above, it is difficult to obtain unambiguous information with respect to these corrosion processes, and in 1991 it was decided to examine the possibility of applying the ICP-MS (Inductively Coupled Plasma- Mass Spectrometry) technique to the analysis of samples arising in the Spent Fuel Corrosion Programme. In short, the technique is based on the ionisation of sample solution constituents in a high temperature plasma followed by mass separation and spectral analysis. In principle, the technique has the potential for the simultaneous analysis of many nuclides in the sample solution, which is clearly advantageous for the study of spent fuel corrosion, since it offers the possibility of obtaining data on many chemical elements, and even isotopic data which could be useful in some cases.

Accordingly, an ICP-MS instrument - a VG PlasmaQuad supplied by Fisons Instruments - was purchased by SKB and commissioned for operation with radioactive specimens during June 1992 in Studsvik Nuclear's Hot Cell Laboratory.

However, the software supplied with the instrument for the correction of isobaric interferences and spectral evaluation was based on a library of elemental isotopic compositions only relevant for the lithosphere. Since the isotopic compositions of the fission product elements are usually significantly different from those of the natural elements, and, together with those of the actinides, are also often dependent on the fuel burnup and irradiation history, this software could not be used for the corrosion programme samples. Hence it was necessary to rapidly develop suitable software for the correction and treatment of the raw counting data collected by the instrument.

Many of the problems associated with the development of such software could have been simplified if methods had been on hand for prior chemical separation of individual elements or groups of elements before introduction into the instrument, but these were not available. It was therefore decided to explore the possibility of performing ICP-MS analysis directly on the specimens arising in the corrosion programme, i.e., in principle, with all fission products and actinides present.

The software developed for this purpose was in the form of a PC-based spreadsheet to which the basic measurement data collected in the instrument during specimen analysis was transferred. In the spread-sheet, corrections were applied first for expected isobaric interferences; two versions of the spread-sheet, based on fission product inventories calculated by the ORIGEN code for fuel burnups of 25.0 and 49.0 MWd/kg U respectively, were developed.

The spread-sheet then calculated the sample concentrations of selected nuclides by means of mass spectrum peak ratios to indium-115, which was added to all specimens prior to analysis, and efficiency calibration factors derived from measurements on a range of natural element standards over a wide mass range, (from Rb to U), and a number of actinide standards. Measurements on the standards were performed at least twice during each sample measurement campaign.

Details of spread-sheet development and the correction procedures have been reported earlier. /1-2, 1-3/

Following an appraisal of the spread-sheet's performance in a limited comparison of results from samples analysed by both the ICP-MS technique and the corresponding "conventional" method, it was introduced into routine use in 1992. Since that time several hundred corrosion test samples have been analysed by the ICP-MS technique.

The solution concentrations for selected nuclides which are calculated in the spreadsheet also require correction for background levels of inactive and radioactive species in the specimens, and in the instrument itself, and procedures for this have been developed and tested using the data available in this large analytical data base. A recent report /1-3/ presents a comparison of the results obtained by the

ICP-MS technique and the corresponding "conventional" analytical methods where this can be performed, i.e., for cesium, strontium, technetium, uranium and plutonium. Although there are measurable statistical biases between the two sets of data in some cases, the comparison suggests that the expanded analytical data base made available by the ICP-MS technique, even by the "direct" solution analysis method used, presents the opportunity for a more detailed evaluation of the results than has been possible hitherto.

Many of the corrosion test samples analysed immediately after commissioning of the ICP-MS instrument were archive samples from previous samplings, including samples from all the earlier contact periods from the Series 11 corrosion tests. This test series (see below) is one of the most important in the whole spent fuel corrosion programme since it consisted of 16 fuel specimens with a wide range of burnups from the same fuel rod so that the possible effects of fuel properties on the corrosion processes could be studied. It was, therefore, of particular interest to apply the broader analytical menu made available by the ICP-MS technique to these samples.

Of course, the results of retroactive analysis of archive solutions of fission products and actinides, although they are acidified before storage, must be used with caution since losses from solution during long-time storage by precipitation and adsorption can be expected. Indeed, such considerations were instrumental in the decision to attempt to rapidly develop direct ICP-MS analysis of radioactive sample solutions in order to avoid even longer storage times.

The plutonium results which are reported in the method comparison programme /1-3/ confirm, in fact, that measurable losses from solution of plutonium, and presumably of other actinides and lanthanides, had occurred in older archive samples. This problem will be discussed more fully below in the context of the data base used for the evaluation.

This report, therefore, presents an evaluation of the presently available results from the Spent Fuel Corrosion Programme, which are compiled in an analytical data base combining the results from the analytical programme and methods used earlier with those from the ICP-MS analytical campaigns.

2 CORROSION TESTS

The SKB Spent Fuel Corrosion Programme performed since 1982 in the Studsvik Hot Cell Laboratory has consisted of a number of experimental corrosion test series of which only 4 test series are considered in this report since the remainder were terminated long before the commissioning of the ICP-MS instrument. The experimental results considered here, however, represent the three reference fuels (2 BWR and 1 PWR) which have been studied in the programme. These four test series are, briefly, as follows;

a) Series 3 Tests: Fuel/clad segments from the Oskarshamn-1 BWR reference rod.
Burnup: 42 MWd/kg U
Sequential static tests under oxidising conditions in deionised water (DW) and the SKB reference simulated bicarbonate groundwater. (GW)

b) Series 32326 Tests: Selected fuel fragments from the same fuel rod as Series 3.
Burnup: 42 MWd/kg U
Sequential static tests under oxidising and anoxic conditions in deionised water (DW) and simulated groundwater with different carbonate concentrations.

c) Series 7 Tests: Fuel/clad segments from the Ringhals-2 PWR reference rod.
Burnup: 43 MWd/kg U
Sequential static tests under oxidising and reducing conditions in deionised water (DW) and the SKB reference simulated bicarbonate groundwater. (GW)
Reducing conditions were established by several methods; by treatment with H_2/Ar in the presence of a Pd/Pt catalyst; by reduction of the water by means of crushed rock, and by flowing H_2/Ar.

d) Series 11 Tests: Fuel/clad segments from a stringer rod from the Ringhals-1 BWR
Burnup: 16 specimens with burnups over the range 27.0 to 48.8 MWd/kg U
Sequential static tests under oxidising conditions in deionised water (DW) and the SKB reference simulated bicarbonate groundwater. (GW)

Full details of the experimental parameters in individual corrosion tests, and tables of the analytical results obtained by the conventional analytical procedures are documented in four internal SKB reports. /2-1, 2-2, 2-3, 2-4/

The test parameters of the corrosion experiments which are included in the present evaluation are collected in Tables A1- A4 in Appendix A. Each table consists of four sub-tables showing respectively, the corrodant solution and the nominal redox state during the test, the duration (in days) of each contact period, and the measured values of the pH and the carbonate concentration (in ppm) of the corrodant solution at the end of each contact period.

Of course, not all the specimens arising from the tests listed in the tables have been analysed by the ICP-MS technique; as will be discussed later, most of the samples examined have been centrifugate samples since some difficulties were encountered with evaluation of the ICP-MS results for membrane filter and vessel strip solutions. Also, only a few samples from the Series 3, 32326 and 7 tests have been analysed in order to cross-calibrate the results before and after the commissioning of the instrument, and to allow a comparison to be made between the three reference fuels.

It will, however, be clearly seen from the compilation of analytical results in the appendices, and which will be discussed in the next section of this report, which samples have results from the extended analytical menu. Alternatively, the report describing the results of the analytical method comparison programme can be consulted. /1-3/

3 CORROSION TEST RESULTS

3.1 COMPARISION OF ANALYTICAL METHODS

As has been explained above, there are now two sets of analytical data available as a basis for evaluation of the corrosion test programme, the results from the "conventional" analytical programme used from 1982, which has been applied to almost all samples, and the results obtained by means of ICP-MS direct analysis of some, but not all, of centrifugate samples, and a few membrane filter and vessel strip solution samples. The degree of agreement between the analytical results obtained by the alternative methods where these can be applied to the same element (U, Cs, Sr, Tc and Pu) has been examined and reported recently /1-3/. The analytical results were compared at the release fraction level, i.e. using the inventory values experimentally determined by each method, and are summarised in Table 3-1.

Table 3-1. Average values of the ratios of ICP-MS results to those from conventional methods. (Series 11 tests only)

Based on independent specimen inventory values

U	Cs	Sr	Tc	Pu
1.09	1.07	1.13	1.02	1.39

The comparison was made using a large number of results from the Series 11 tests, which represented a stringent test of the data, since the inventory values for the 16 specimens had been determined by interpolation between values determined experimentally on fuel pellets from the two ends of the fuel pellet column from which the corrosion test specimens were taken.

Inspection of the ratios in the table shows that the ICP-MS results for uranium and the fission products tend to be somewhat higher than those for the conventional methods, while for plutonium the ICP-MS results were 39% higher on average. Some of these biases are undoubtedly due to the fact that, with the exceptions of the analysis of uranium and technetium, different isotopes are measured in the ICP-MS methods than in the corresponding conventional methods /1-3/, as is shown in Table 3-2.

Table 3-2. Nuclides measured in the ICP MS and conventional methods.

Method	Cesium	Strontium	Plutonium
ICP-MS	Cs-133, Cs-135	Sr-88, Sr-90	Pu-240
Conventional	Cs-137	Sr-90	Pu-239, Pu-240

The main reason for the apparent biases between the methods is that there are significant differences in the specimen inventories determined by the two methods for the 5 elements used in the method comparison. As is discussed in the method comparison report, the differences can be partly explained by the fact that the ICP-MS inventories were determined on new fuel specimens taken later from the same fuel rods (Series 3 and 7), or on stored archive solutions (Series 11). However, it is possible that effects specific to the ICP-MS methodology, such as mass discrimination, concentrations in the plasma or the calibration technique, also contribute to the observed differences.

When the analytical results were compared using the same inventory values, the average ratios shown in Table 3-3 were obtained.

Table 3-3. Average values of the ratios of ICP-MS results to those from conventional methods. (Series 11 tests only)

Adjusted to common specimen inventory values

U	Cs	Sr	Tc	Pu
1.09	0.96	0.96	0.96	1.22

It is now seen that for the 3 fission products there is only a 4% difference between the results from the different methods, while there is still a significant difference for the plutonium results. The result ratios for uranium analysis are unaltered since the same inventory values are used in both methods.

The 22% difference between the plutonium results has been discussed in detail in the method comparison report /1-3/, where it was pointed out that both the two Pu analytical methods are associated with background correction problems. In the alpha spectrometric method, background correction of the 5.15 MeV peak, which is used for plutonium measurement, is complicated by low-energy side tailing of the larger 5.50 MeV peak. The extent of the background contribution due to the tailing effect varies from specimen to specimen since it depends on the amount of residual solids on the counting disk. In the case of the retroactive ICP-MS analysis of the Series 11 archive solutions, obviously it was not possible to correct the results for the corrosion test specimens for measured background levels in the batch of corrodant solutions used in the tests since these were no longer available. Hence, arbitrary standardised backgrounds from measurements on batches prepared after commissioning of the instrument were also used for correction of the results from the earlier contact periods. The errors involved in this simplified procedure are quite significant when the sample solution plutonium levels are low, as in many of the corrosion test samples.

Returning now to the result ratios in Table 3-1, since it is difficult to choose one set of inventory values as the more "accurate", it was decided that for these five elements, the average between the release fraction values, where results from both methods were available, would be used as basis for the evaluation process.

3.2 ICP-MS ANALYSIS OF OTHER NUCLIDES

In the version of the PC spread-sheet used for the correction for isobaric interferences and calculation of solution concentrations for the samples considered in this report, satisfactory correction procedures have not yet been developed for all the mass peaks. The concept "satisfactory" in this context implies that good agreement is obtained between the values of release fraction derived from different isotopes of the same element. The corrections used are based on ORIGEN calculations of fission product inventories in fuel at only two burnup levels, (see the Introduction), and become increasingly more complicated and uncertain in mass ranges where there are many isotopes, or where there is more sensitivity to the fissile nuclide mix.

For example, satisfactory agreement has not been attained for Ru and Pd, which have isotopes which lie on the higher mass side of the lower peak in the fission yield versus mass curve, and are, therefore, particularly sensitive to variation in the fraction of fissions occurring in plutonium. It would, perhaps, be useful if reliable results for Ru and Pd were available for comparison with those of Tc and Mo in order to obtain more complete data on the corrosion behaviour of the fission product metal inclusions. However, although the release fractions calculated from different isotopes for Ru and Pd show significant differences (occasionally factors of 3 or 4), their concentrations in centrifugates are very low. As will be shown later in this report, release fractions for Tc and Mo are usually (relatively) large, and even accurate Ru and Pd data would not change the conclusions reached during the evaluation. The release data for these two elements and for Rh, which shows similar behaviour, has, therefore, not been included in this report.

Other omitted fission products are yttrium (Y-90 is measured, but its release behaviour partly reflects Sr-90 behaviour), cadmium (large spread between isotope results), tellurium and iodine. The latter element, iodine, would be useful to have in the collected data, and concentrations of I-129 in the centrifugates are often measurable. However, there are serious reservations against use of the data, largely because of suspected losses of iodine from the samples during even short storage times prior to analysis.

The correction procedures for Ba-138 used in the spread-sheet (isobaric interferences), and for natural background subtraction, however, appear to function fairly satisfactorily, and give release data which can be used for comparison with the Sr data. The Ba-138 concentration derived in the spread-sheet must be corrected for its component in the natural barium background present in the corrodant solution. The natural Ba background has been calculated for all specimens by means of their measured Ba-136/Ba-138 ratios. This ratio is significantly different for barium of natural isotopic composition and for mixtures of fission product isotopes as calculated by ORIGEN. The ratios are small, and are also sensitive to the fuel specimen burnup, and the accuracy of the calculated natural barium background is, therefore, subject to some uncertainty, particularly for low concentration samples.

The release behaviour of **rubidium** is of interest for comparison with that of cesium, and two fission product nuclides, Rb-85 and Rb-87, are in principle available for this purpose The natural rubidium background in corrosion test solutions can be calculated by a similar type of internal isotope dilution analysis to that used for barium, i.e., based on ORIGEN-calculated Rb-85/Rb-87 fission product ratios. The method appeared to function well on most samples, giving good agreement between the release fractions for the two isotopes, after subtraction of the calculated natural Rb and Sr-87 backgrounds. It was noticed, however, that for samples from early contact periods between fuel and corrodant solutions - particularly the first two contacts in the Series 11 tests - the method calculated unreasonably high values for the Rb background levels. After some thought, it was realised that this effect was due to different release mechanisms for the two Rb isotopes during the first contacts with water. It has been shown /3-1/ that rubidium migrates to the grain boundaries of the fuel during irradiation, and thus, like cesium, shows a high release to the corrodant during the first weeks of contact. The Rb-85 isotope, however, which is formed by the beta decay of Kr-85, is also deposited on fuel and clad surfaces from the Kr-85 released to the fuel rod free volume during irradiation, and during the storage time prior to opening the rod for the measurement of fission gas release. The rapid dissolution of this deposited Rb-85 enhances the release of this isotope relative to that of Rb-87. This effect will be discussed later. However, as a consequence of this observation, standardised rubidium backgrounds, the averages of the values calculated for later water contacts, were used for correction of the early corrosion test specimens.

Molybdenum, together with Tc, Ru, Rh and Pd, is a constituent of the 4d metal fission product inclusions which are found in irradiated fuel. For the determination of its release fraction by the ICP-MS technique, the average of the values calculated for four Mo isotopes, of masses 95, 97, 98 and 100, is used. The agreement between the individual values is usually very good.

The **rare earth** fission products, as a group, constitute a significant fraction of all fission products, as weight or number fraction. On the basis of the results of much experience of post-irradiation examination of spent fuel, they are considered to be homogeneously distributed in the fuel, and they would be excellent monitors of the dissolution rate of the fuel matrix, if they were not solubility limited in the corrodant solutions used in the programme. The spread-sheet calculates the sample concentrations of a number of nuclides which are of potential interest for evaluation purposes; La-139, Ce-140, Pr-141, Nd-143, -144, 145, -146, Sm-152, Eu-153 and Gd-156. However, many of the rare earth nuclides have fairly large cross-sections for neutron capture, and there is appreciable uncertainty regarding the general validity of the inventory values calculated by ORIGEN which have been used for the isobaric interference corrections.

A more serious criticism of the rare earth data collected in the retroactive analysis campaign is that the solution concentrations calculated in the spread-sheet, for many samples are about the same level as the standardised backgrounds /1-3/ used for correction, giving negative values of release fraction for a fairly large number of samples. This, of course, is the same problem as that for plutonium and the other actinides which was discussed in section 3.1 above, but is an unavoidable conse-

quence of the decision to perform the retroactive analysis campaign. The release fraction results for the rare earth elements, therefore, are of doubtful value but are included in the evaluation to permit a comparison with values from future analysis. Only values for **La, Ce, Pr, Nd and Eu** are included in the compilation. Some gamma spectrometric results for Ce and Eu release fractions (larger values only) are available and show surprisingly good agreement with the corresponding ICP-MS results.

The ICP-MS background correction problems discussed above also have a serious adverse affect on the measurement of americium and curium, confirming the earlier conclusion /3-1/ that the chemical separation of these elements prior to ICP-MS analysis is advisable. Thus, the **curium** results used in this evaluation have almost all been selected from the results obtained by the alpha spectrometric analysis of Cm-244. Unfortunately, this alternative is not possible for americium, since, as mentioned earlier, the 5.50 MeV peak in the alpha spectra includes contributions from both plutonium and americium.

Although the same ICP-MS background subtraction procedure was also applied to the analysis of **neptunium**, the centrifugate concentrations of this element are usually much higher than those of Am and Cm, and meaningful results can be obtained.

3.3 RESULT COMPILATION

In order to facilitate direct comparison of the behaviour of different elements, the analytical results of all samples, - centrifugates, membrane filters and vessel strip solutions - have been compiled in the form of **release fractions**, and are presented in Appendix B. With the exception of rubidium, for which the release fractions in centrifugates are given for both Rb-85 and Rb-87 (see above), the data is tabulated according to chemical element since the release data is often the average of results from two or more isotopes. The elements selected for the compilation, based on the discussions in section 3.2 above, are shown in Table 3-4, together with an indication of the analytical techniques used.

Table 3-4. Chemical elements included in the release fraction compilation.

	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
ICP-MS	x	x	x	x	x	x	x	x	x		x	x	x	x	x
OTHER		x	x			x	x		x	x		x			x

Following the discussion in section 3.1 of the biases between the release fraction results for U, Cs, Sr, Tc and Pu obtained by the ICP-MS technique and those from the conventional methods, it was decided to use the averages of the results from the two methods as the basis for evaluation. This principle has also been applied, where relevant, to the other elements listed in the table.

However, there are some important exceptions to this principle. Only numerical results have been used in the evaluation so results of the type "less than" or "not detected" are not acceptable and in such cases the results from the alternative method, if available, have been selected. Negative results for release fractions, for example those caused by doubtful background correction procedures, have been deleted from the tables to facilitate legibility.

Since it has been demonstrated that significant losses of plutonium from solution had occurred in long-stored archive solutions /1-3/, the alpha spectrometric values of release fraction have been selected for all archive solutions. In other samples, the average values have been used. As mentioned above, almost all the curium values in the tables are also values obtained by the alpha spectrometric method.

Although, as mentioned above, the evaluation will be mainly based on the tabulated release fractions, and on cumulative release fractions and release rates, some attention will be paid to the **centrifugate molarities** of the actinides and lanthanides. A tabulation of such values is presented in Appendix C. The molarities have been calculated by means of the centrifugate volumes, the release fractions in Appendix B and the inventories of individual fuel specimens (in moles/specimen) presented in Appendix D. This appendix also lists the inventories of key nuclides in individual fuel specimens which were determined by ICP-MS analysis of inventory specimen solutions.

The tabulated values of moles/specimen are calculated values, since not all isotopes of the listed elements are measured by the present ICP-MS/spread-sheet procedure. For the lanthanides, the cited values are based on the measurements of key nuclides in the inventory specimen solutions, together with the ratios calculated by ORIGEN of the key nuclides to the other unmeasured isotopes.

For the actinides plutonium, americium and curium, the inventory values are also derived from measurements on key nuclides (Pu-240, Am-243 and Cm-244) in the inventory specimen solutions. In this case, these measurements were complemented by measurements on isotopic composition of the separated plutonium to give values of inventories of the chemical elements. It can be noted here that for the Series 11 fuel specimens the tabulated values have been obtained by interpolation of the results on the inventory specimens. Further, it must be remembered that not all the tabulated values are constant with time, but change due to the growth and decay processes of the radioactive isotopes. This effect, however, is neglected in this report, since all measurements, on corrosion test samples and on inventory specimens, were performed during roughly the same period of time.

3.4 ACCURACY

It is clear from the discussions in the preceding sections that it is difficult to quote values for the accuracy of the tabulated results. For a particular nuclide, the concentrations in the samples arising in the programme can vary by five or six orders of magnitude; the samples, at least when analysed without prior chemical separations, are of varying complexity with regard to their constituent elements; the tabulated results in the appendices are a mixture of average values of several analyses, and

results of single analyses. (In order to limit the analytical work-load and instrument contamination during the ICP-MS retroactive analysis campaign, the early Series 11 samples were only analysed once.) Further, the procedure used for constructing the unified tables of release fractions measured by different analytical methods, which have been shown to yield results differing significantly, itself possibly introduces uncertainties of the order of 5 - 10%.

In the recent report on comparison of the results of the different analytical methods /1-3/, it was shown that, for corrosion tests on fuel/clad segment specimens, the ICP-MS results displayed good linearity with the conventional method results down to values of release fraction of about E-05. At lower concentrations, there was increasing scatter in the results.

In the corrosion test programme, after several years of water contact, the contact periods were usually lengthened to several hundred days. A measured release fraction of E-05 in such a test would correspond to a fractional release rate of somewhat lower than E-07 /day, which is about the level of the rates observed for Cs, Rb, Sr, Ba and Mo release to the bicarbonate groundwater under both oxic and anoxic conditions. The comparison of release rates of these and other nuclides, for example in order to investigate whether or not congruent dissolution is occurring, will be an important part of the evaluation presented in section 6 of this report. In the absence of definite values of analytical accuracy, it is first at this stage in the evaluation, when the degree of convergence between release rates of several elements can be examined and compared, that a subjective judgement can be made of whether or not the results are sufficiently accurate for the purposes in hand.

For very low release fractions, for example those for actinides and lanthanides, and for uranium and technetium in experiments performed under anoxic or reducing conditions, the evaluations will be based on groups of results rather than individual results.

4 SPENT FUEL SPECIMENS

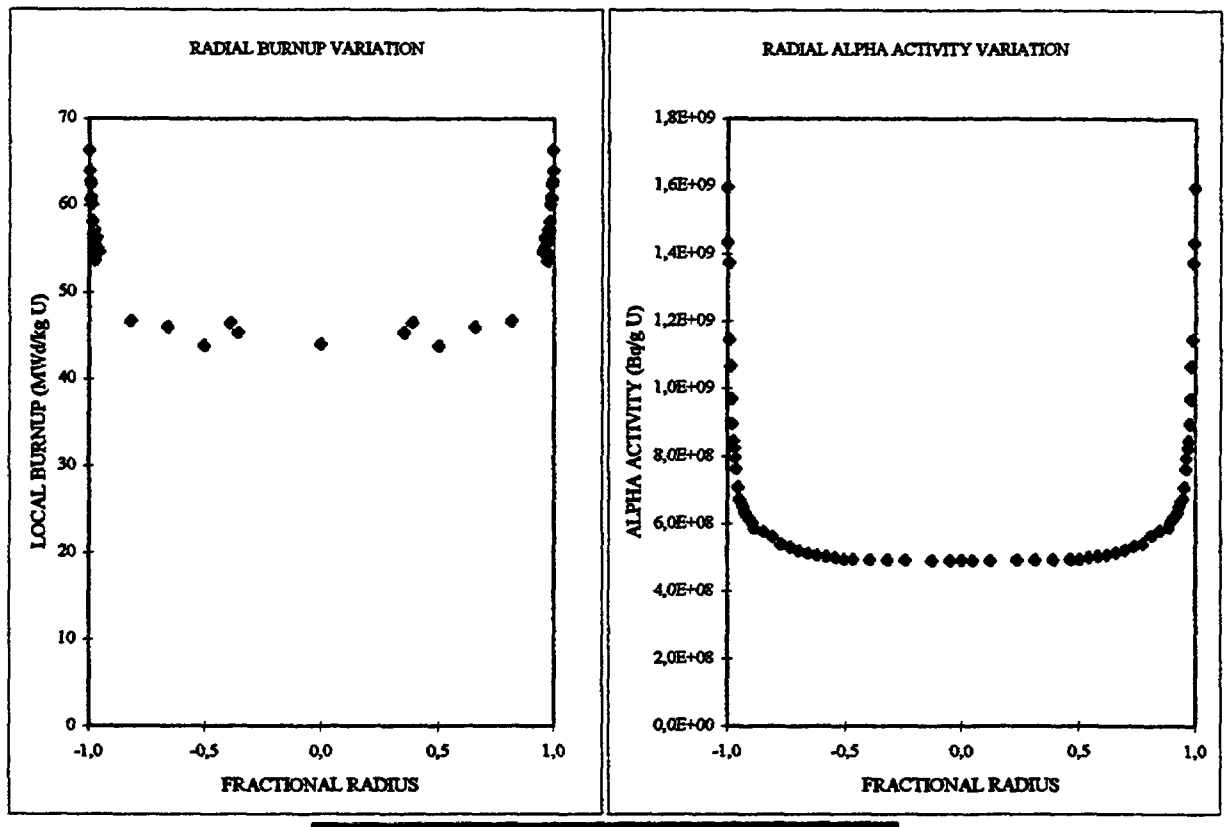
One of the parameters varied in the Spent Fuel Corrosion Programme is the spent fuel itself, or rather, the source of the fuel (BWR or PWR), the burnup and linear heat rating of the fuel specimen (its irradiation history) and the experimental procedure used in effecting contact with the corrodant solution (as fuel/clad segments or as fragments of fuel). The properties of spent nuclear fuel which are of most significance for its corrosion in groundwaters have been reviewed and discussed in a recent report /4-1/, which also presented the results of detailed fuel characterisation studies on the three reference fuels used in the corrosion programme.

As has been mentioned in section 2 of the present report, two of these reference fuels consist of one BWR fuel rod and one PWR fuel rod of burnups 42.0 and 43.0 MWd/kg U respectively, and have been used in the Series 3 and 32326 corrosion tests (BWR) and Series 7 corrosion tests (PWR). Although there are some differences in burnup between the fuel specimens used in these corrosion tests and the respective nominal value, they are fairly small and have been ignored in the evaluation, unless specifically referred to.

The third reference fuel consisted of the lower segment of a stringer rod from the Ringhals-1 BWR, which, because of the neutron flux gradient, contained fuel with burnups ranging between 20 and 49 MWd/kg U. The 16 fuel specimens from this rod, which were used in the Series 11 corrosion tests, had burnups varying from 27.0 to 48.8 MWd/kg U, and were very suitable for the study of the effects of fuel properties on corrosion behaviour. The life-averaged linear power of the 16 Series 11 fuel specimens ranged from 9.4 to 16.9 kW/m, which can be compared with values of 18.4 and 17.7 kW/m for the Series 3 and Series 7 fuels respectively. (Note, however, that such a comparison has very restricted relevance, since in practice the variation of linear power during the irradiation can have relatively large effects on fuel structure and migration processes.)

One of the experimental aims of the Series 11 experiments was to study the possible migration of fission product strontium to grain boundaries during irradiation by measuring the Sr-90 release rate as a function of varying pellet linear heat rating. Since all the pellets in the test came from the same rod, the fuel burnup became a second variable, and thus, a second experimental aim was to study the effect of burnup on fuel corrosion behaviour. Of particular interest in this respect were the so-called rim effects which occur in fuel pellets during irradiation. These effects are illustrated in Figure 4-1 by the some of the results of the fuel characterisation work performed on the fuel pellet in the Series 11 fuel rod which had the highest linear power rating.

The figure presents curves showing the radial variation within the fuel pellet of both the burnup and the total alpha activity at the time of the measurements.



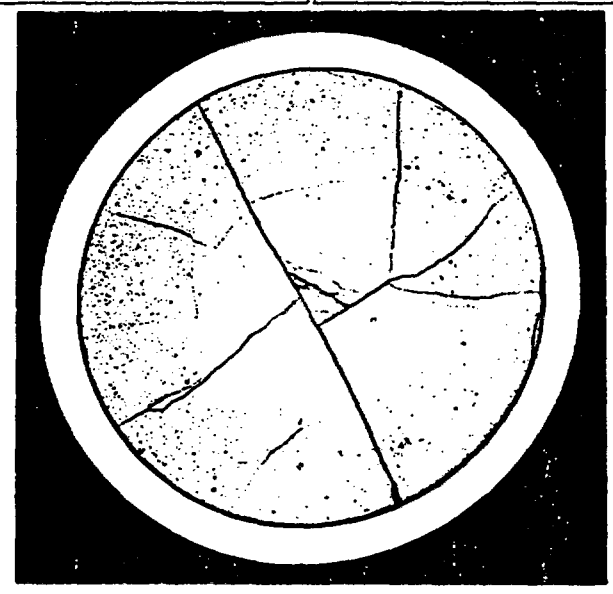


Figure 4-1. Illustration of the pellet rim effect in pellet 47 (Burnup 49.0 MWd/kg U) of the Series 11 corrosion tests.
Above left) The variation of burnup across the pellet diameter.
Above right) The variation of total alpha activity across the pellet diameter.
Below) Polished cross-section. (x 6)

During the irradiation of UO_2 fuel pellets, there is a build-up of plutonium at the pellet rim due to resonance capture of neutrons in the epithermal range, and this results in steep gradients of both burnup and alpha activity in this zone. Note that these effects occur at all levels of burnup, but, for a particular fuel pellet, increasing burnup leads to a higher fraction of the fission events occurring in isotopes of plutonium, and to a build-up of higher mass isotopes of other actinides (usually with shorter half-lives) due to multiple neutron capture reactions and beta decay. Thus, as can be seen in Figure 4-1, the radial distribution of alpha activity is much steeper at the rim than the corresponding curve for burnup.

This has marked consequences for the fuel pellets in the segment rod used for the Series 11 corrosion tests, and constitutes an important parameter which is varied in this test series. Under the anoxic or reducing conditions which are expected in the future Swedish deep-rock repository for spent nuclear fuel, oxidation and dissolution of the fuel due to alpha radiolysis of the water in the immediate proximity to the fuel surface could represent the main corrosion process /4-2/. In the figure, it is seen that in pellet 47 the alpha activity is about 3 times higher at the pellet rim than at the pellet centre which would indicate that corrosive attack would be favoured at the pellet rim.

Two other fuel pellets, with burnups of 36.7 and 21.2 MWd/kg U, in the segment rod used for the Series 11 corrosion tests were also examined in the fuel characterisation programme /4-1/, and the results from these examinations have been used in Figure 4-2 to illustrate the variation of the fuel's alpha activity over all the 16 fuel specimens used in the Series 11 tests.

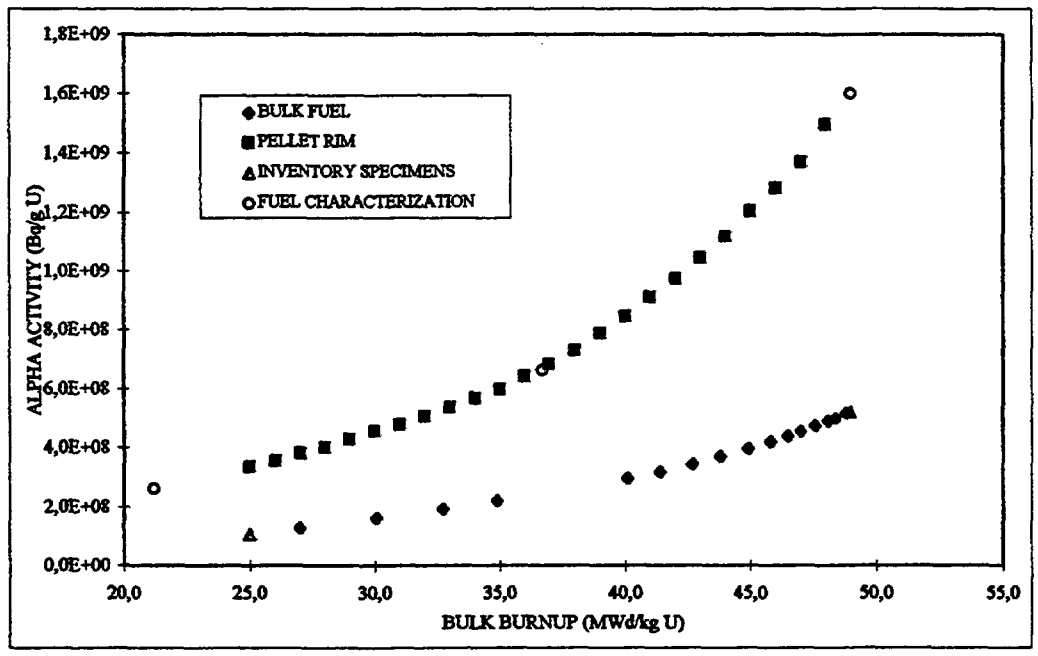


Figure 4-2. Fuel specimens for the Series 11 corrosion tests: Comparison of the total alpha activity (Bq alpha/g U) at the fuel pellet rim and in the bulk fuel.

The curve showing the variation along the pellet stack of the alpha activities at the pellet rim has been calculated by interpolation of the values measured on the 3 fuel characterisation specimens. These values are compared with the alpha activities of the bulk fuel (representing a complete cross-section of the fuel pellet) for each of the 16 fuel/clad specimens, which were calculated from the individual actinide inventories obtained by interpolation between the experimentally measured values in the two inventory specimens. Note, however, that the specific alpha activity at the pellet centre is somewhat lower than the bulk fuel value.

Clearly, the potential for alpha radiolysis, as measured by the local alpha activity, is seen to vary by about a factor of 15 over the 16 fuel specimens, i.e., from the pellet centre of the lowest burnup pellet to the rim of the highest burnup pellet. The beta activity in each fuel pellet also shows a maximum at the pellet rim due to the burnup gradient, but because of the longer range and smaller absorbtion of beta particles in water, their radiolytic effect is less localised than for alpha particles.

Another radially-varying ratio in the fuel pellets, the U-236/U-235 ratio, will be discussed briefly here since it may be useful as an indicator of corrosion site and is usually measurable in centrifugate solutions by the ICP-MS technique. Although it is difficult to measure in the solid pellet, the U-235 content of the fuel decreases by fission and neutron capture reactions as irradiation proceeds, while the U-236 content increases. The relative rates of these reactions are governed by the neutron spectrum effects mentioned above, and are expected to result in a radial profile of the U-236/U-235 ratio somewhat similar to the burnup profile shown above in Figure 4-1.

In the BWR reference fuel used for the Series 3 corrosion tests, values of the isotopic ratio over a range between 0.95 and 1.4 were measured on randomly selected fuel particles and pellet rim scrapings /4-1/, but it was not possible to establish to which values of radius these results corresponded. Such experimental data is not available for the Series 11 fuel specimens, but it will be assumed arbitrarily later in this report that there is an increase of about 30% in the U-236/U-235 ratio at the pellet rims compared with the pellet centres for these fuels.

Apart from the rim effects discussed above, which essentially refer to the radial distributions of fission products and actinides, even changes in the fuel microstructure, occurring at or near the pellet rim, are observed in irradiated fuel /4-1/. However, the structural changes appear only in fuel with a value of bulk fuel burnup exceeding a somewhat varying threshold within the range 40-45 MWd/kg U.

The most noticeable structural change is the formation of a zone of high porosity at the pellet rim, and such zones have been observed at the peripheries of pellets from the reference BWR (42.0) and PWR (43.0 MWd/kg U) fuels, (Series 3 and 7 corrosion tests respectively). Of the three ceramographic specimens examined from the Series 11 segment rod, with bulk burnups of 21.2, 36.7 and 49.0 MWd7kg U, a porous rim zone was observed only in the 49.0 MWd/kg U specimen.

In addition to the zone of high porosity, the fuel pellet rim is also associated with a zone showing loss of definable grain structure in a process where the original fuel grains sub-divide into numerous smaller grains. In the case of the 49.0 MWd/kg U specimen, the zone containing significant populations of the sub-grains extended more than 200 microns into the pellet from the periphery, but traces could be found even at positions 1.5 mm from the rim. In this pellet the zone of high porosity was only about 20 microns wide.

During similar SEM examination of the Series 11 ceramographic specimen with a burnup of 36.7 MWd/kg U, no high porosity zone and no loss of definable grain structure were observed at the rim. Thus, if these structural changes have a measurable effect on the corrosion behaviour of spent fuel, such effects could only be expected in those corrosion tests with fuel specimens in the series with burnups higher than 36.7 MWd/kg U, i.e., fuel specimens 11-5 to 11-16.

So far in this section, only certain intrinsic properties of spent fuel pellets have been considered. However, the physical form of the fuel specimens, particularly those aspects which determine the degree of contact between the fuel surfaces and the corrodant solution, will also be discussed here in order to give further background information necessary for the evaluation of the experimental results.

As has been mentioned above, almost all the fuel specimens used in the corrosion tests considered in this evaluation have been in the form of fuel/clad segments, usually about 20 mm in length. During the corrosion tests, the specimens were suspended in a spiral of platinum wire in (usually) 200 cm^3 of the selected corrodant. Hence, direct physical contact between the fuel specimen and the corrodant is limited to the fuel surfaces at the two open ends, the free volumes represented by the cracks in the fuel itself and the residual pellet/clad gap, as can be seen in the polished transverse cross-section of the pellet in Figure 4-1.

Values of the rod free volume - the sum of the last 2 terms, pellet cracks and the residual pellet/clad gap - can be estimated /4-1/ at a given pellet position from the results of profilometry measurements and clad compression measurements on the intact fuel rod prior to cutting out the fuel specimens. For the 16 fuel/clad specimens for the Series 11 corrosion tests, which had burnups ranging from 27.0 to 48.8 MWd/kg U, the estimated free volume in a 20 mm long fuel/clad segment varied from about **0.06 cm^3** at the low burnup end to about **0.04 cm^3** at the high burnup end. The average rod free volume before irradiation was about 0.07 cm^3 in a 20 mm long segment.

The free volume in the PWR reference fuel/clad segments (also 20 mm long) used for the Series 7 corrosion tests was estimated to about **0.01 cm^3** since in this rod diametrical clad creepdown had also reduced the volume.

Clearly, these volumes are very small compared with the total corrodant volume of 200 cm^3, but this was accepted during planning of the tests, which were designed to give a relatively close simulation of repository conditions. However, the limited access of the corrodant to the open fuel porosity and grain boundaries, further reduction of access due to precipitation from uranium saturated solutions, and

mixing of the egressed corrodant with the 200 cm^3 reservoir must be considered in the evaluation of results.

Finally, it can be pointed out that polished fuel cross-sections as in Figure 4-1 can give a misleading impression of the fuel/clad specimens, which were cut out from the rod using pipe-cutters. Thus, the course surface and chipped fuel fragments of a PWR specimen shown in Figure 4-3 are more typical of the specimens used. Also, each fuel/clad segment contains fuel fragments of varying size and morphology, as is shown in Figure 4-4.

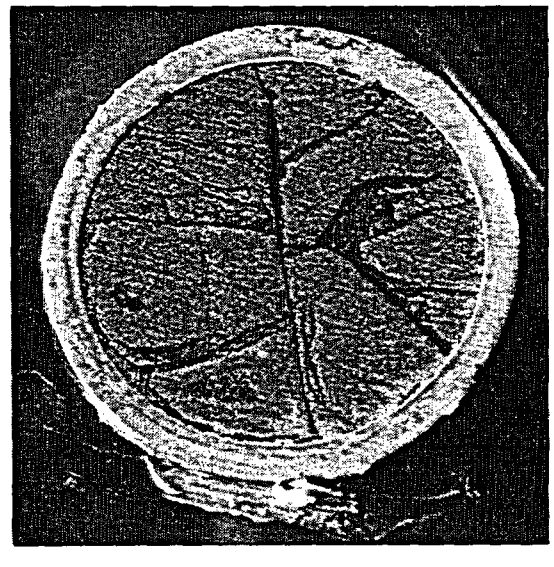


Figure 4-3. Open end of a PWR fuel/clad specimen from the Series 7 corrosion tests. (x 6)

Figure 4-4. Fuel fragments from the BWR reference fuel. (x 3)

5 CORROSION TEST PROCEDURES

In a short description of the corrosion test procedures in the Introduction to this report, it was mentioned that the analytical programme was applied to samples from three fractions originating at the conclusion of each corrosion test contact period, i.e., centrifugate, membrane filter and vessel strip solution. Thus, the centrifugation of the corrodant solution through the membrane filter /1-1/ yielded a centrifugate which was free of fuel fines, while it was hoped that analysis of the other two fractions would give useful data on possible colloid formation, and on precipitation and absorption processes in the corrosion vessel.

It was pointed out in the preceding section that the fuel specimens, whether in the form of fuel/clad segments or as fuel fragments, are always associated with small amounts of fuel fines. Since the specimens are in direct contact with the corrodant water sample, and are subjected to movement during the sample preparation operations, there is a significant possibility of "contamination" of the membrane filter and vessel strip fractions by these fuel fines.

Further, as was pointed out above, the compilations of selected analytical results on filter and strip samples in Appendix B, are incomplete, since many of the samples were not analysed by the ICP-MS technique.

In this section, therefore, the analytical results on membrane filter and vessel strip solution samples will be briefly evaluated, partly in order to examine the possibility of their contamination with fuel fines, and partly to attempt to develop correction factors which can be applied later to the results from centrifugate analysis.

5.1 VESSEL STRIP SOLUTIONS

The probability for the occurrence of precipitation and/or adsorption effects during corrosion tests in deionised water or the simulated bicarbonate groundwater would be expected to increase with increasing fuel/water contact times. In order to test this hypothesis, the total uranium contents (in micrograms) in the vessel strip solutions from corrosion tests performed in simulated groundwater under oxic and anoxic conditions, and in deionised water are presented in Figures 5-1, 5-2 and 5-3 respectively. Since the duration in days of the contact periods normally, but not always, increased as the sequential corrosion test proceeded, the uranium weights are plotted against the corresponding cumulative contact time (CUTI in the result tables in the appendices). This method, therefore, presents the results from a given specimen test series in the correct chronological order, i.e., in the order of sample taking, but the figures can be somewhat misleading for comparison between results from programmes with different patterns of contact period durations.

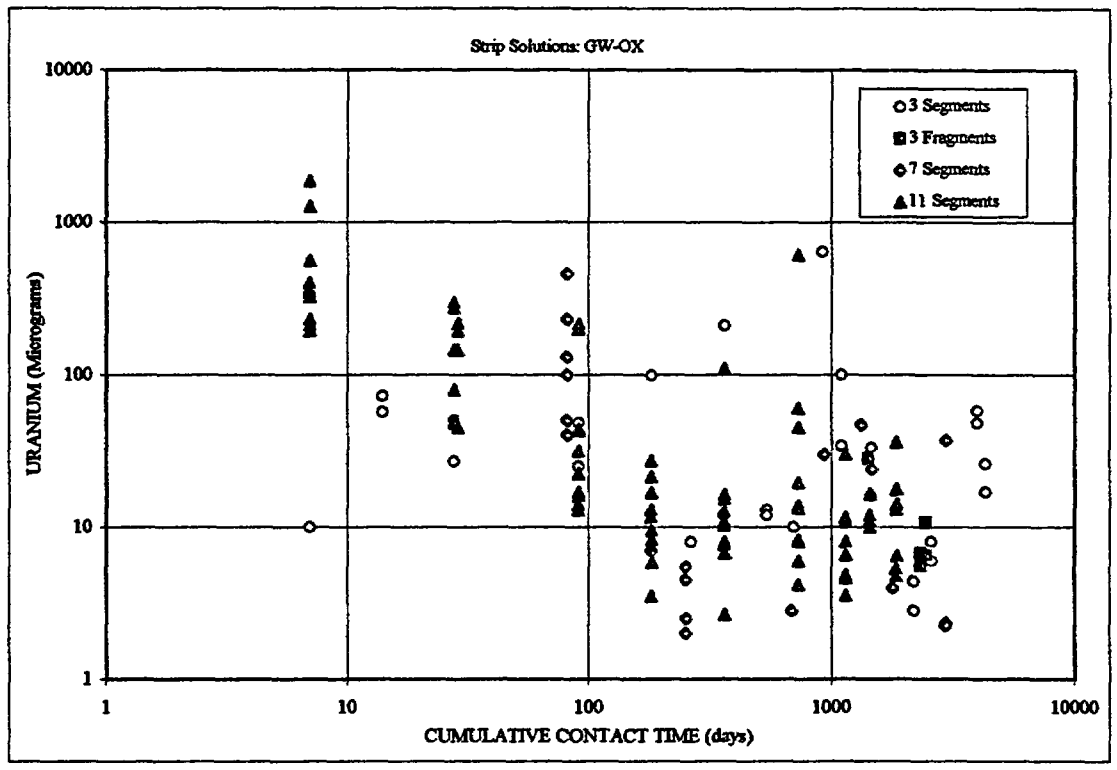


Figure 5-1. Total uranium contents (micrograms) of vessel strip solutions from corrosion tests performed in groundwater (GW) under oxic conditions.

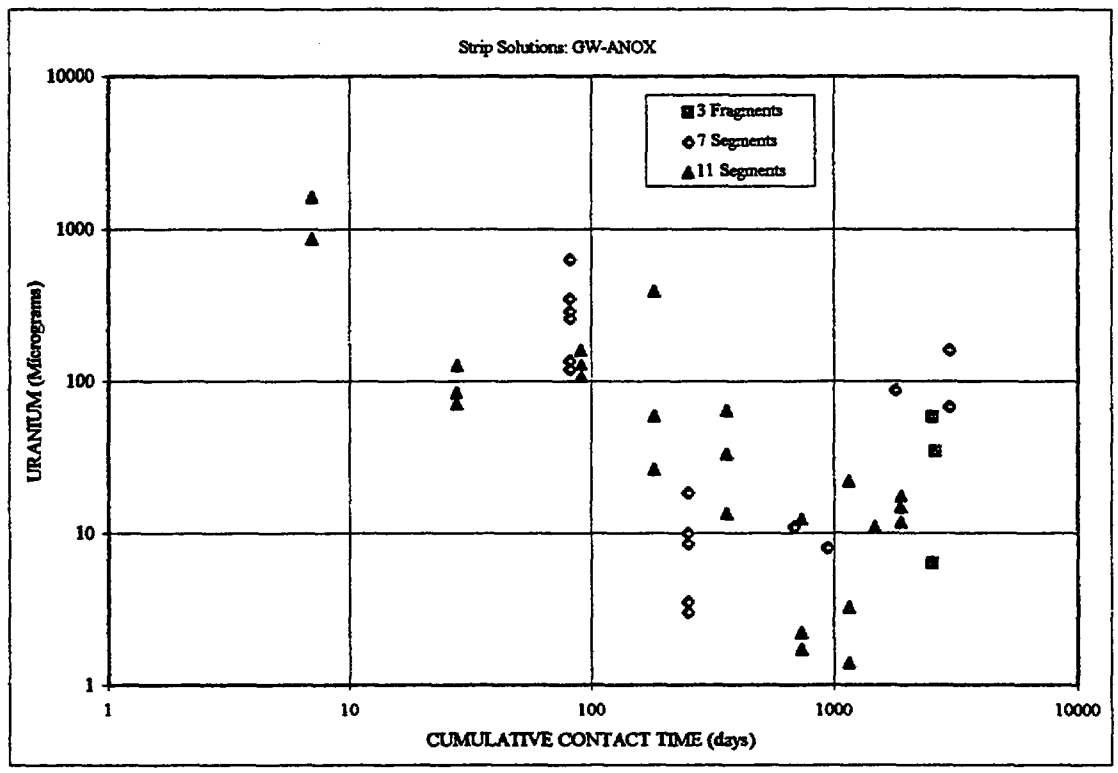


Figure 5-2. Total uranium contents (micrograms) of vessel strip solutions from corrosion tests performed in groundwater (GW) under anoxic conditions.

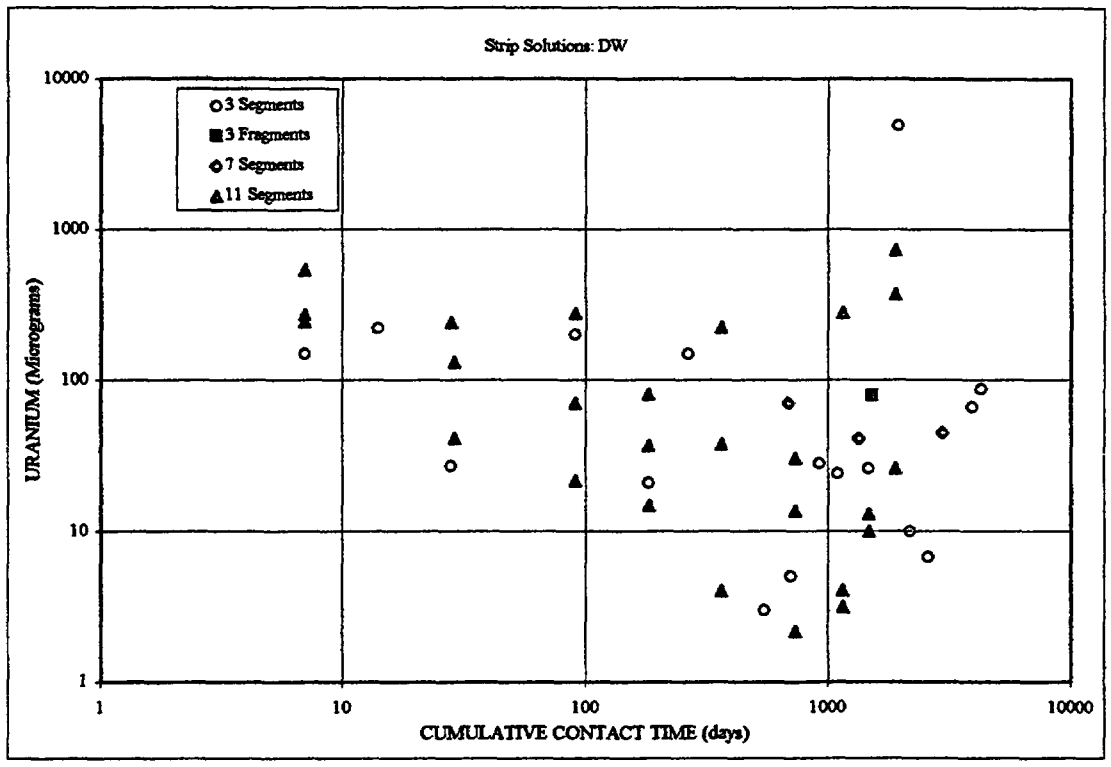


Figure 5-3. Total uranium contents (micrograms) of vessel strip solutions from corrosion tests performed in deionised water (DW).

The data in all three figures show large scatter, some of which is caused by the choice of cumulative time as the abscissa variable, since the samplings plotted for the Series 3 fragments and the Series 7 fuel/clad segments occurred later in the corrosion tests compared with the Series 11 results. Clearly, however, there is a trend towards lower uranium contents in the vessel strip solutions as the number of contact periods increases, which would suggest that the primary source of the uranium in the solutions is due to dissolved fuel fines, shaken or washed out of the fuel specimens during the handling in the hot-cell during the sampling procedure or experimental start-up.

For the 10 fuel/clad segment specimens used in the Series 11 GW-OX corrosion tests, the total uranium found in all 9 of the vessel strip solutions analysed in the sequential tests, varied from about 0.3 to 2.2 mg, with no apparent correlation with specimen burnup. On average, about 76% of the total uranium weight was found in the first two vessel strip solutions, that is, those from the shortest contact periods of 7 and 21 days duration at the start of the corrosion tests.

However, although this is convincing evidence that the source of most, if not all, the uranium in the vessel strip solutions is fuel fines, it is also necessary to investigate the actinide and fission product contents in the strip solutions in order to confirm or modify that conclusion.

In Figures 5-4 and 5-5, the available release fraction data for the actinides Np, Pu and Cm in vessel strip solutions has been compared with the corresponding release fractions for uranium for corrosion tests performed in the simulated bicarbonate groundwater under oxic and anoxic conditions respectively. The figures also show the line which demonstrates a 1:1 ratio between release fractions.

However, it should be noted here that such comparison of release fractions is strictly only valid for samples corresponding to bulk fuel, i.e., on a complete cross-section of the fuel pellet, since all release fraction values are derived from inventory values determined by destructive analysis of whole fuel pellets. In the discussion of fuel and fuel pellet properties in the preceding section, it was shown that, due to the rim effect, the local burnup varies by about 60% over the pellet diameter, and hence the local fission product and actinide inventories also show similar variations, but for individual nuclides these can be both smaller or larger than 60%. Since it is usually difficult to define unambiguously the origin within a fuel pellet of the material in a given specimen, the comparison of release fractions is associated with appreciable uncertainty. Note that these comments also apply to centrifugate and membrane filter samples.

With these comments, and the discussion earlier in this report of the accuracy of actinide measurements, in mind, inspection of Figures 5-4 and 5-5 suggests that there appears to be reasonable agreement between the release fractions for U, Np, Pu and Cm over about 3 orders of magnitude of release fraction (or solution concentration) and this can be interpreted as evidence that the vessel strip solutions consist mainly of fuel fines.

When the comparison of release fractions is extended to fission products, however, it appears that some precipitation and/or adsorption effects are evident. In this evaluation the comparison is made between the release fractions for U, as above, with the release fractions of 4 fission product elements which will be discussed later in this report with respect to defining congruent or non-congruent dissolution, i.e., Rb, Cs, Sr and Ba. The results for vessel strip solutions for corrosion tests performed under oxic and anoxic conditions are presented in Figures 5-6 and 5-7 respectively.

As in the actinide comparison discussed above, there are close similarities between the results for corrosion tests performed in groundwater, regardless of whether they were performed under oxic or anoxic conditions.

It is also seen that the results for strontium are in reasonable agreement with the uranium release fractions, and thus with the behaviour of the other actinides. For cesium and barium, however, and to a lesser extent rubidium, there are large deviations from a 1:1 relationship with uranium release, even considering the comments on inventory variations discussed above.

In order to investigate this effect, the release fractions for the fission products have been corrected by subtraction of the contribution equivalent to the corresponding uranium release fraction, giving in effect a measure of the "excess" release fraction

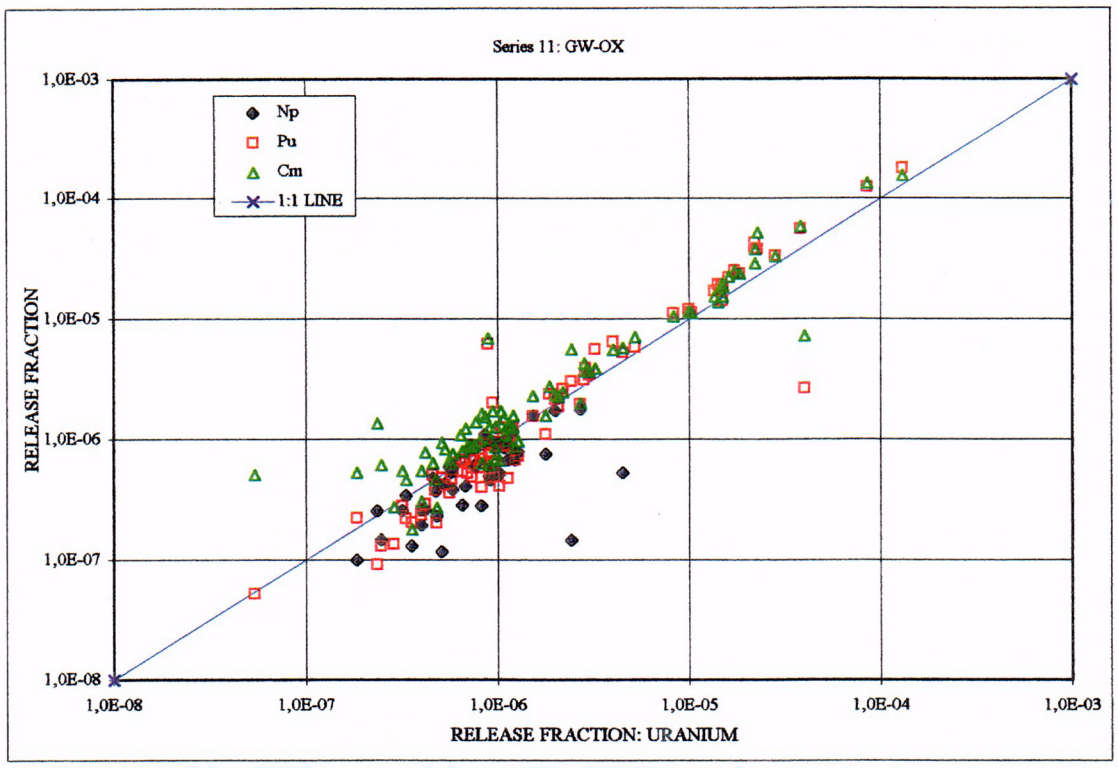


***Figure 5-4**. Comparison of release fractions; U versus other actinides in vessel strip solutions from corrosion tests performed under GW-OX conditions.*

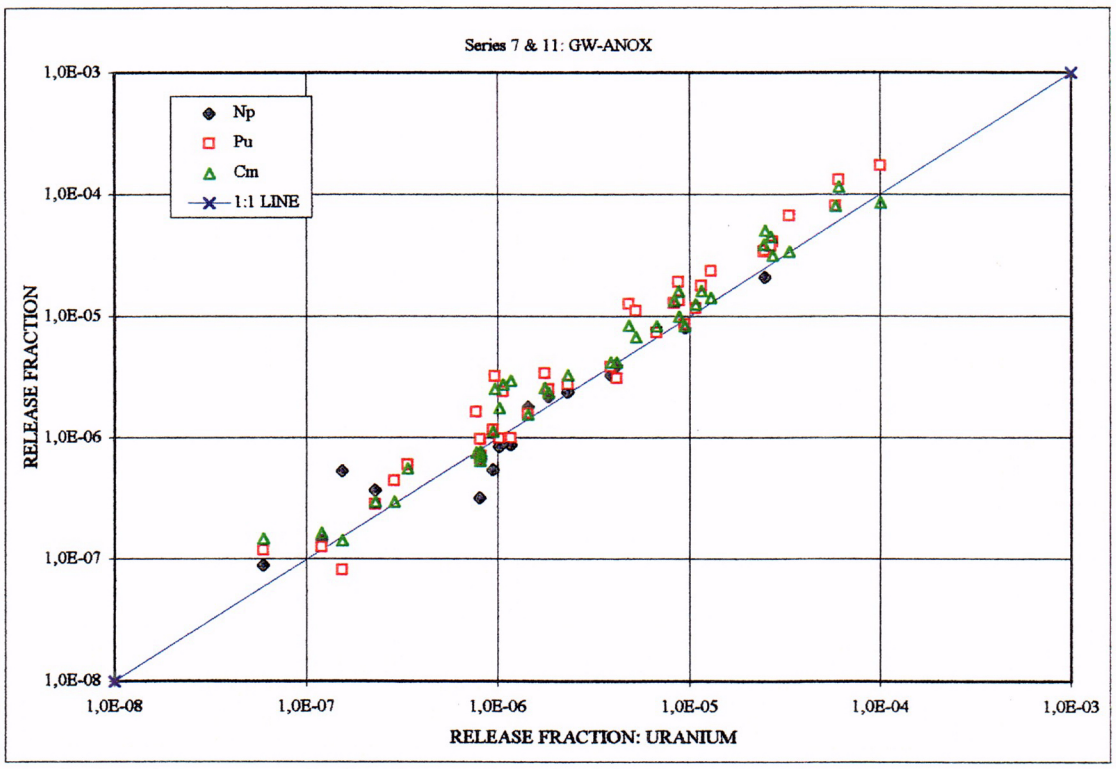


***Figure 5-5**. Comparison of release fractions; U versus other actinides in vessel strip solutions from corrosion tests performed under GW-ANOX conditions.*

C01

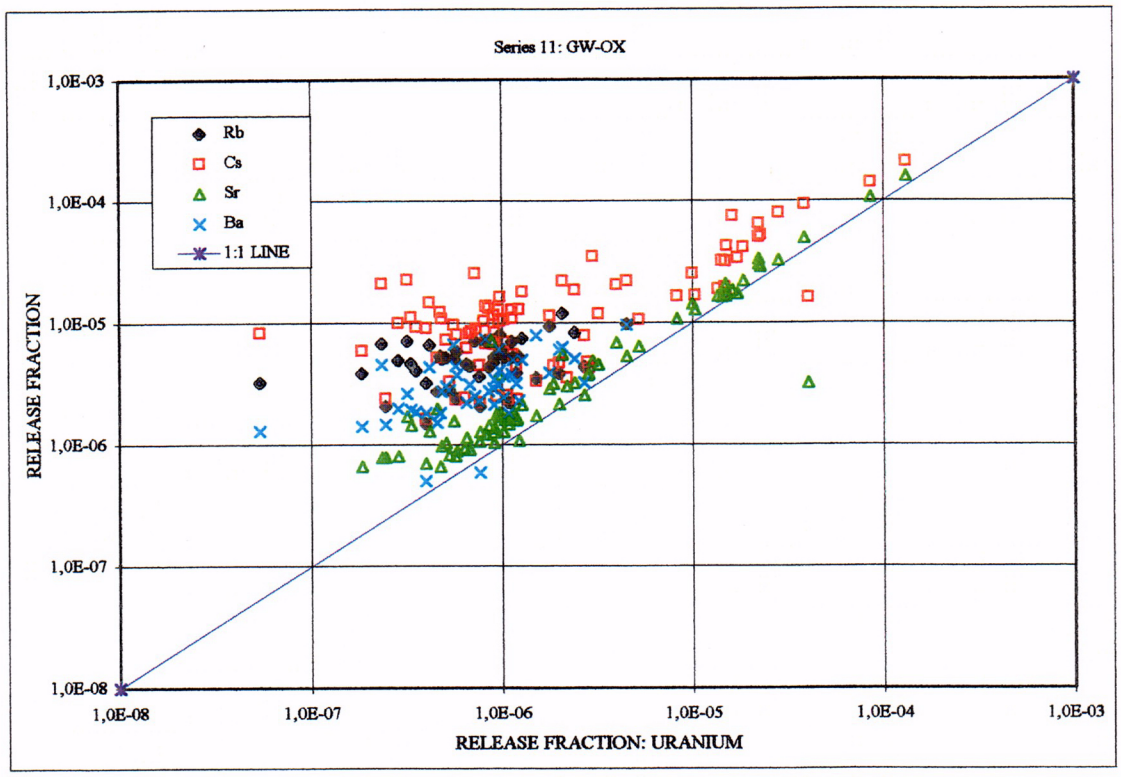


Figure 5-6. *Comparison of release fractions; U versus selected fission products in vessel strip solutions from corrosion tests performed under GW-OX conditions.*

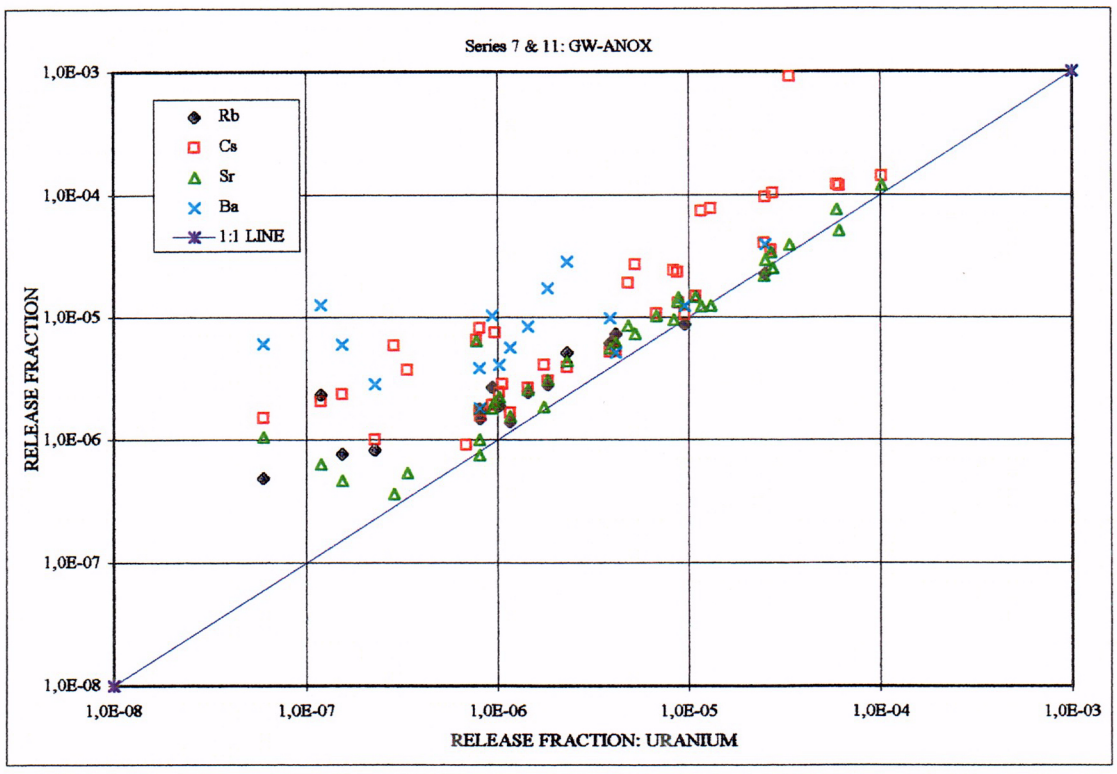


Figure 5-7. *Comparison of release fractions; U versus selected fission products in vessel strip solutions from corrosion tests performed under GW-ANOX conditions.*

C02

assumed to be due to precipitation or adsorption in the corrosion test vessel. Although there is some scatter in the data, the values of "excess" release fraction are clearly proportional to the release fractions in the corresponding centrifugates, and there seems to be no consistent correlation with contact time between fuel and corrodant water.

Average values of the ratios between the "excess" release fractions in the vessel strip solutions and the corresponding centrifugate release fractions from corrosion tests performed in the simulated groundwater (oxic and anoxic conditions) are presented in Table 5-1. Ratios for Mo and Tc are included in the Table together with the values for Rb, Cs, Sr and Ba.

Table 5-1. Average values of the ratios between the "excess" release fractions in the vessel strip solutions and in the corresponding centrifugates.

	Rb	Cs	Sr	Ba	Mo	Tc
GW-OX	0.019	0.027	0.015	0.052	0.008	0.006
GW-ANOX	0.043	0.035	(0.151)	0.093	0.069	(0.730)

Clearly, the values of the ratios are in general quite small - corresponding to a few percent of the centrifugate release fractions - and may partly represent a few residual millilitre of centrifugate remaining in the corrosion vessel prior to introduction of the strip solution /1-1/. The high ratios for Sr and Tc in GW-ANOX tests, however, are based on a few results with large scatter, and in the case of Tc are the result of comparison with very low centrifugate release fractions.

Somewhat higher values of the ratios are listed for Ba, and for all the fission products in the GW-ANOX tests, but the quality of the data is probably not adequate for a definite acceptance of their correctness.

The discussion above has concerned only tests performed in groundwater. As can be seen in the collected test parameters in Appendix A, although analytical data is available for about 50 corrosion tests performed in deionised water, under both oxic and anoxic conditions, the various series of sequential contact periods have included unplanned low pH periods (due to contamination in the hot-cell), and planned contact periods with groundwater. Because of these perturbing effects, the deionised water results often show abrupt trend changes, sometimes revealed in contact periods subsequent to the initiating event. Thus, the results from these tests must be evaluated in smaller groups to avoid confusing generalisations.

However, in order to permit a qualitative comparison with the groundwater test results, the release fractions for actinides and for selected fission products in vessel strip solutions from DW-based corrosion tests are compared with the uranium release fractions in Figures 5-8 and 5-9.

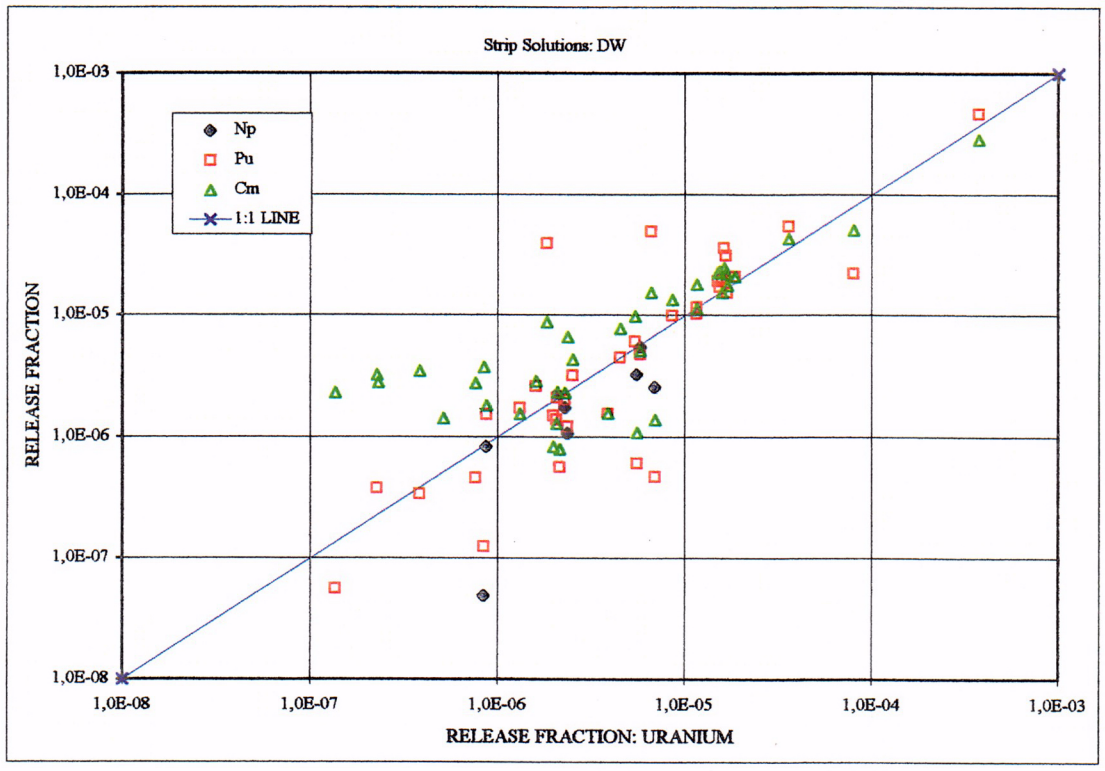


***Figure 5-8**. Comparison of release fractions; U versus other actinides in vessel strip solutions from corrosion tests performed in DW.*

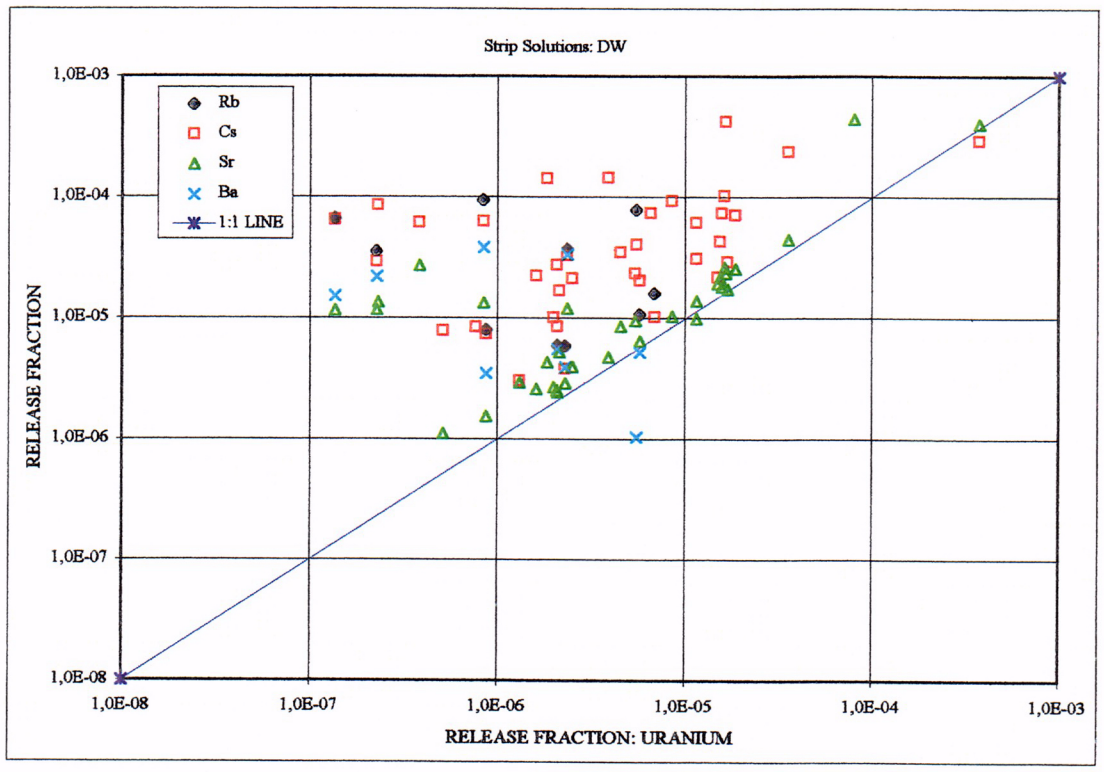


***Figure 5-9**. Comparison of release fractions; U versus selected fission products in vessel strip solutions from corrosion tests performed in DW.*

C03

5.2 MEMBRANE FILTER SPECIMENS

In the sampling procedure for centrifugation through membrane filters, 10 cm^3 of corrodant solution, after removal of the fuel specimen, is sampled by pipette, avoiding proximity to the bottom of the corrosion vessel. Thus, if the membrane filters also retain fuel particles from the corrodant solution, these are very unlikely to be particularly large, which can be the case for the vessel strip solutions discussed above.

Figures 5-10, 5-11 and 5-12 present the analytical results for uranium retained on the membrane filters for corrosion tests performed in groundwater under both oxic and anoxic conditions, and tests performed in deionised water respectively. Note that the values plotted represent the uranium calculated for the total volume of corrodant solution, which was usually 200 cm^3.

Comparison of the figures with Figures 5-1, 5-2 and 5-3, the corresponding figures for the vessel strip solutions, shows that the uranium retained on the filters is one to two orders of magnitude lower than the uranium found in the strip solutions, and that there is no observable trend with cumulative contact time. There is also a great deal of scatter in the results, which is mostly due to the very low amounts of uranium measured in the individual membrane filters. Since only 10 cm^3 of the corrodant solution was centrifuged through each filter, the total uranium measured was usually less than 5 micrograms, and at this level there was a significant variation between the results from duplicate or triplicate analyses. The results tabulated in Appendix B are the average values of multiple analyses.

The results from corrosion tests performed in deionised water (Figure 5-12) show particularly large scatter, and a much wider range of values of measured retained uranium. As for the corresponding vessel strip results, detailed examination of the results indicated that it is necessary during evaluation to consider individual results rather than using general factors. Thus, comparison of the uranium release fractions with those for the actinides and selected fission products has again been limited to the results of corrosion tests performed in groundwater.

Actinide and fission product data from tests in simulated groundwater under oxic conditions are presented in Figures 5-13 and 5-14, and the corresponding data for anoxic conditions are presented in Figures 5-15 and 5-16.

Clearly, there is much more scatter in the experimental data for the actinides than was observed in the corresponding figures for the vessel strip solutions, even when results at about the same level of release fraction are compared. It is possible that this reflects differences in efficiency for the removal of different species from the filters during the acid leaching procedure prior to analysis, /1-1/ It can also be noted that the alpha spectrometric method for the determination of plutonium is subject to severe background subtraction problems in this type of specimen, with low Pu counting rates in the presence of higher levels of Cm isotopes, but it is surprising that the scatter is larger for the plutonium release fractions in the GW-OX tests, than in the GW-ANOX tests. However, the release fractions for Np, Pu and Cm do not appear to be significantly larger than those for U in the membrane filter specimens.

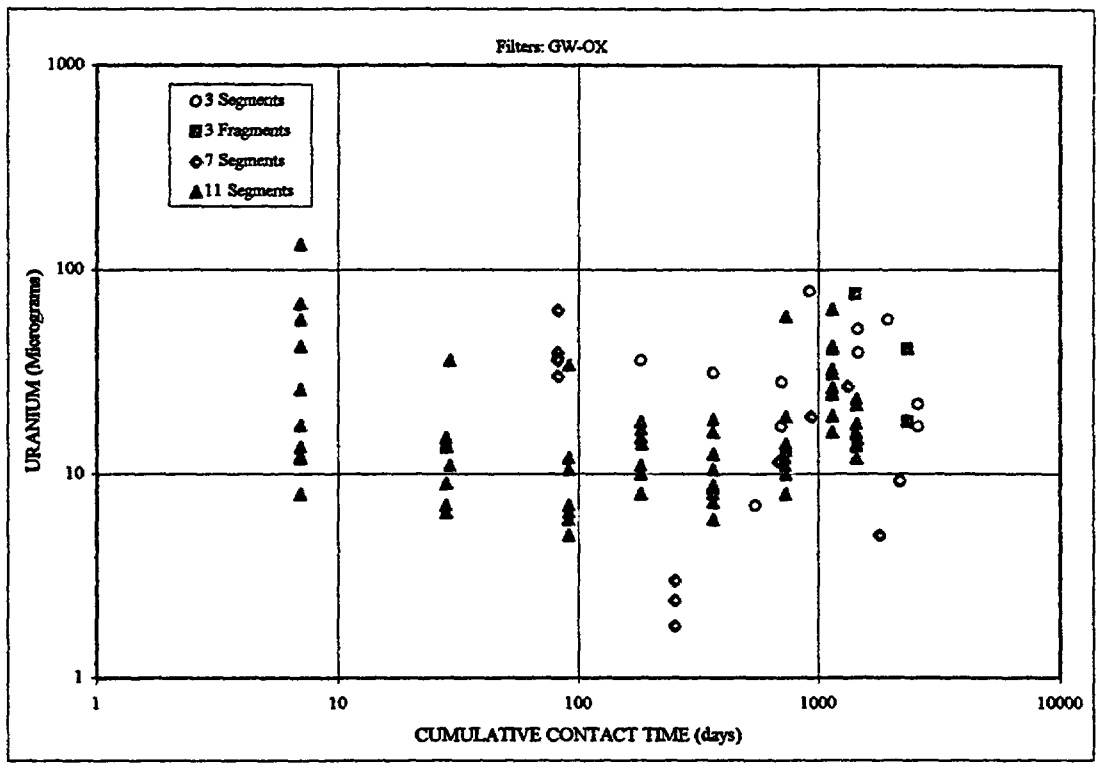


Figure 5-10. Uranium on membrane filter specimens. (Calculated for total volume of corrodant solution.) Tests under GW-OX conditions.

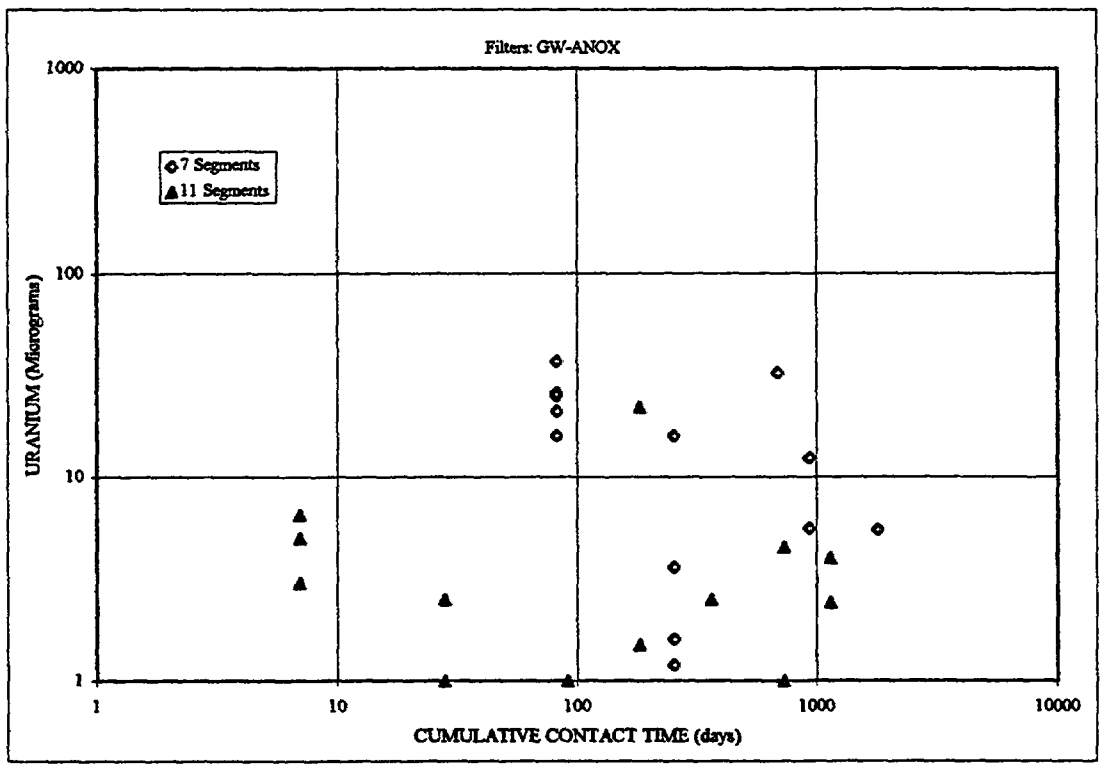


Figure 5-11. Uranium on membrane filter specimens. (Calculated for total volume of corrodant solution.) Tests under GW-ANOX conditions

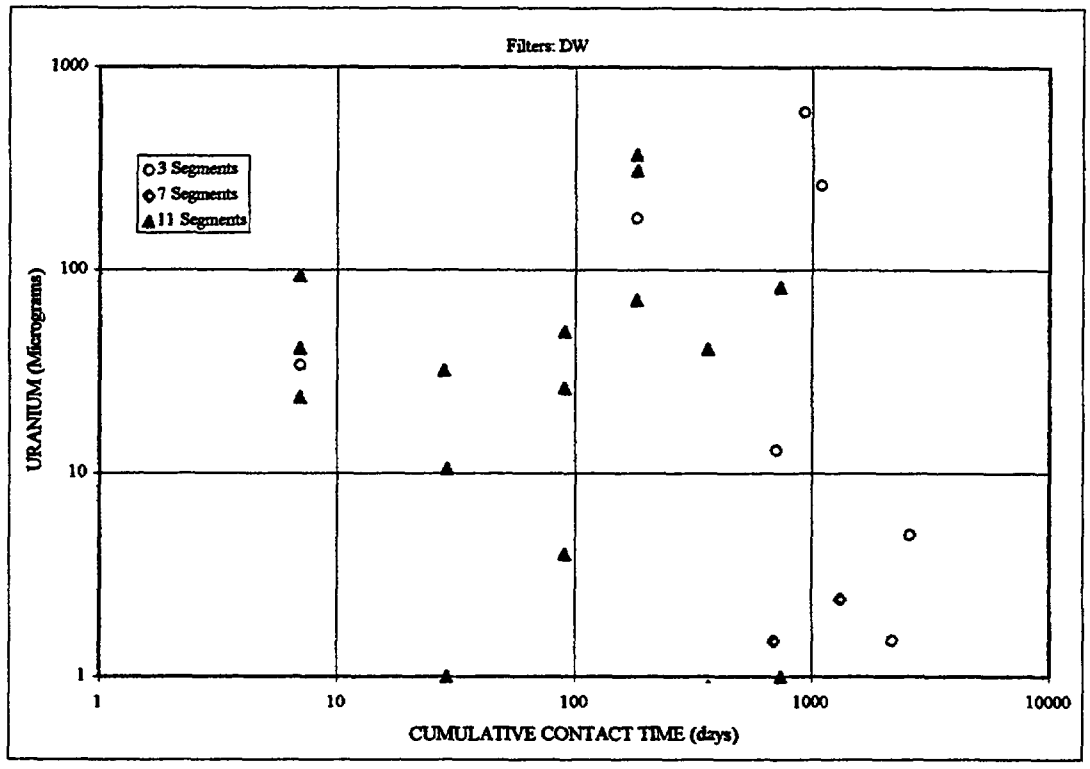


Figure 5-12. Uranium on membrane filter specimens. (Calculated for total volume of corrodant solution.) Corrosion tests using deionised water. (DW)

As in the case of the vessel strip solutions, much of the scatter in the fission product data is due to its correlation with the release fractions in the corresponding centrifugates rather than with the U release fractions on the membranes. Therefore, the same procedure of subtracting the U release fractions was used to calculate the "excess" release fractions for the fission products, thus assuming that they were selectively retained on the filters in proportion to the total concentration in the corrodant solution. There was too little data available for Rb and Ba, but the average values for the ratios between release fractions in the membranes and the centrifugates for Cs, Sr and Tc in tests under oxic conditions, and for Cs and Sr under anoxic conditions are presented in Table 5-2. The average value for Sr under anoxic conditions is shown in parentheses because of appreciable scatter.

Table 5-2. Average values of the ratios between the "excess" release fractions in the membrane filter specimens and in the corresponding centrifugates.

	Cs	Sr	Tc
GW-OX	0.037	0.102	0.043
GW-ANOX	0.044	(0.203)	

Together with the values in Table 5-1, these ratios can be used in the discussion of release fractions and rates in centrifugates in the next section, since in the possible absence of experimental values, they can be used to estimate release fraction values for the vessel strip and membrane filter fractions.

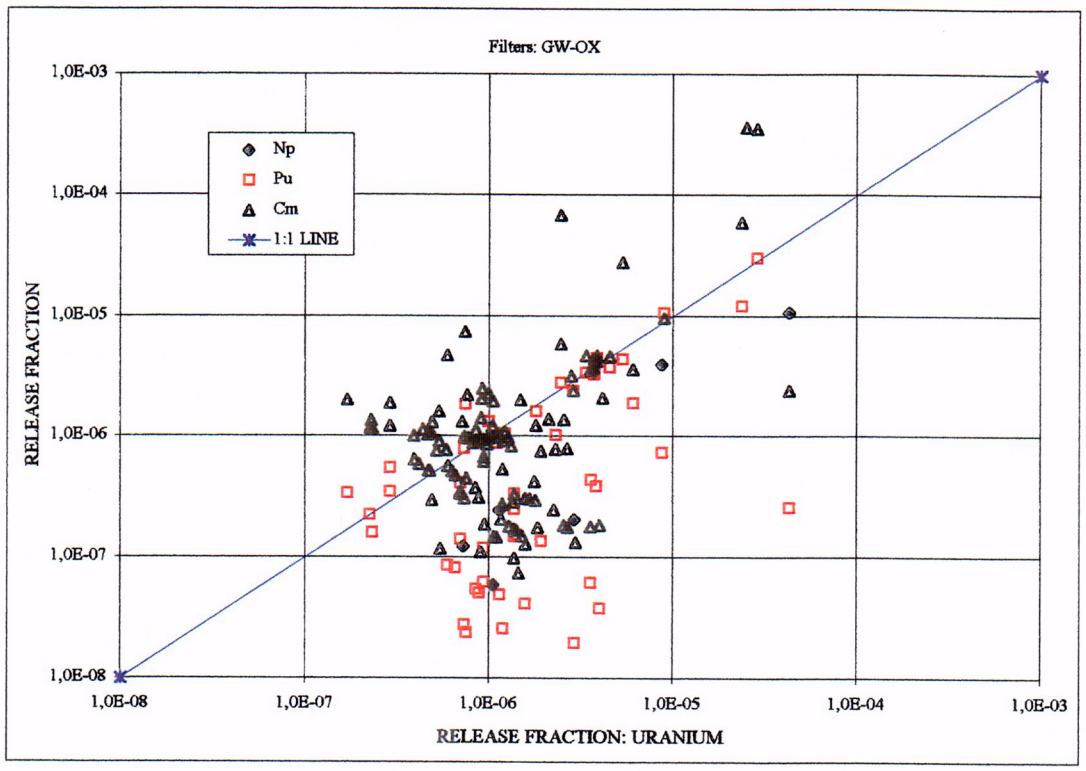


Figure 5-13. *Comparison of release fractions; U versus other actinides in membrane filter specimens from corrosion tests performed in groundwater under oxic conditions. (GW-OX)*

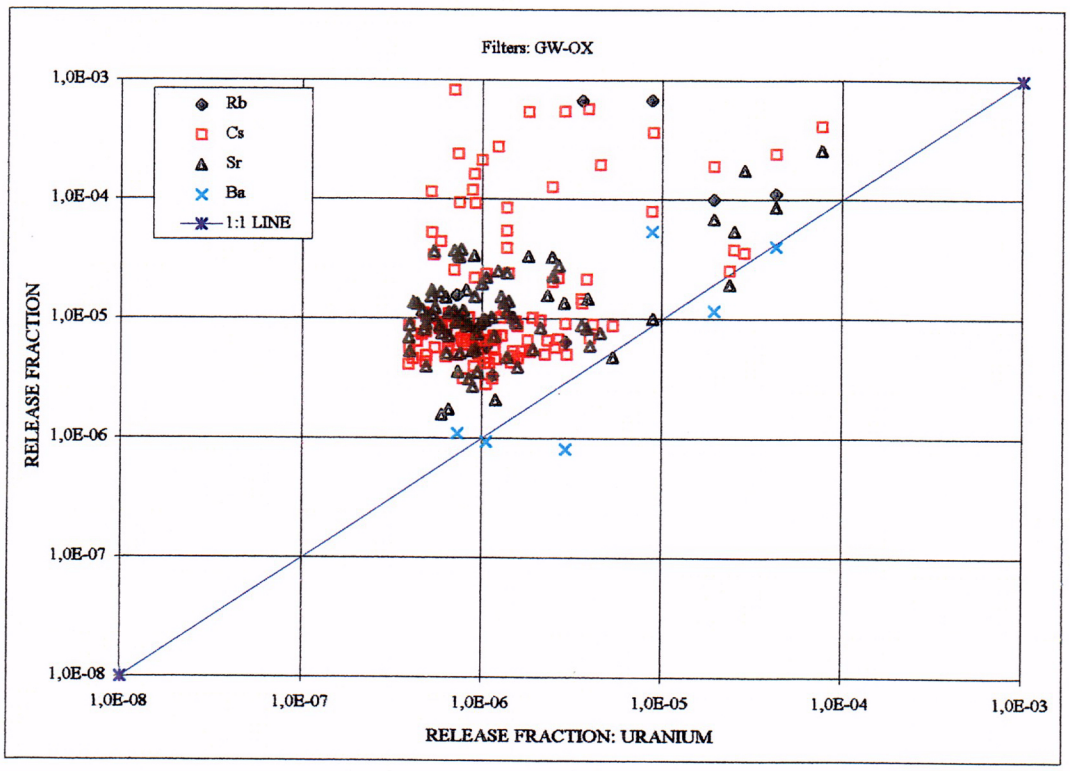


Figure 5-14. *Comparison of release fractions; U versus selected fission products in membrane filter specimens from corrosion tests performed in groundwater under oxic conditions. (GW-OX)*

C04

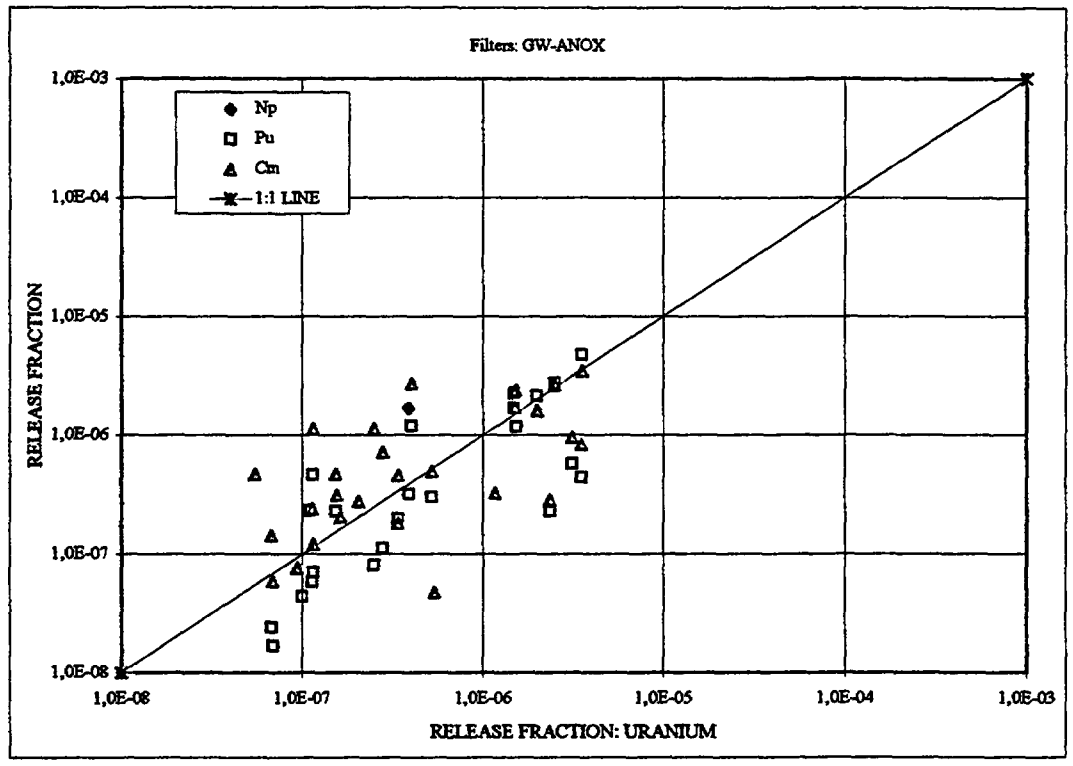


Figure 5-15. Comparison of release fractions; U versus other actinides in membrane filter specimens from corrosion tests performed in groundwater under anoxic conditions. (GW-ANOX)

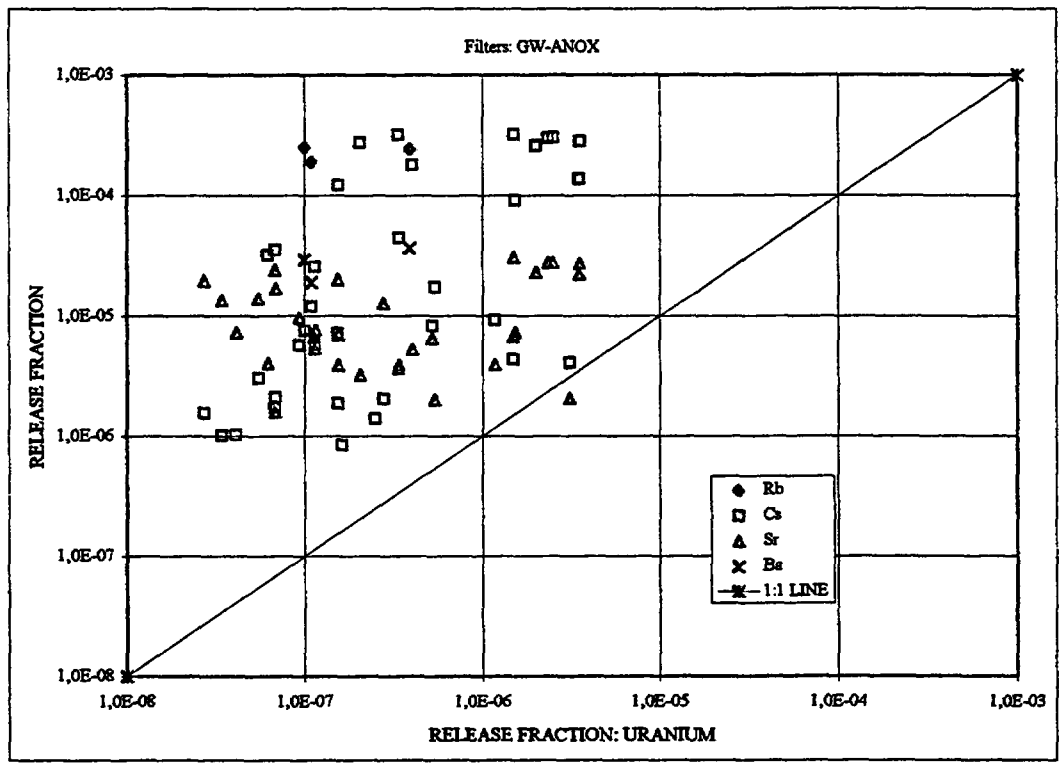


Figure 5-16. Comparison of release fractions; U versus selected fission products in membrane filter specimens from corrosion tests performed in groundwater under anoxic conditions. (GW-ANOX)

6 EVALUATION

Because of the wide burnup range of the fuel specimens in the Series 11 corrosion tests, and the extensive programme of characterisation of the fuel specimens used, the interpretation of the analytical results from these tests are of central importance for the evaluation of the programme as a whole. As has been mentioned earlier in this report, most of the retroactive application of the ICP-MS analytical technique has been directed at archive samples, mostly centrifugates, from this test series in order to obtain a broader data base to facilitate such evaluation. To some extent, therefore, in this report the results of the Series 3 and 7 tests have been regarded as tests of the general validity of the conclusions reached for the Series 11 tests.

The following evaluation will be almost entirely based on the tabulations of release fractions collected in Appendix B. These release fractions have also been used to calculate fractional release rates and molarities when required. Most attention has been devoted to consideration of the results for centrifugates which usually contain almost all the material released during corrosion. Results for membrane filter specimens and vessel strip solutions will be used either in the form of the tabulated individual results or in the form of general factors such as those discussed in section 5. For convenience, the evaluation has been divided into sub-sections with separate but related themes.

6.1 CUMULATIVE RELEASE FRACTIONS

As mentioned above, the 16 fuel specimens in the Series 11 corrosion tests were all from the same fuel rod, but had different linear heat ratings and burnups. One of the main aims of the experiments was to examine the possible migration during irradiation of fission products to fuel grain boundaries, which could result in enhanced release to the corrodant due to selective attack.

In Table A-4 in Appendix A it can be seen that ten of these fuel specimens, with burnups ranging from 27.0 to 48.8 MWd/kg U, were subjected to nine consecutive contact periods in the SKB simulated bicarbonate groundwater /1-1/ under oxic conditions, with a total contact time of 5.09 years. The cumulative release fractions for selected fission products and uranium in the 9 centrifugates for each specimen are plotted in Figure 6-1 as a function of the specimen burnup. Note that the range of burnups also corresponds to a range of life-averaged linear powers from 9.4 to 16.9 kW/m.

The extended analytical data base made available by combining the results obtained by means of the ICP-MS technique with those from the earlier methods permits the comparison of the behaviour of three fission product "pairs"; cesium and rubidium; molybdenum and technetium; and strontium and barium.

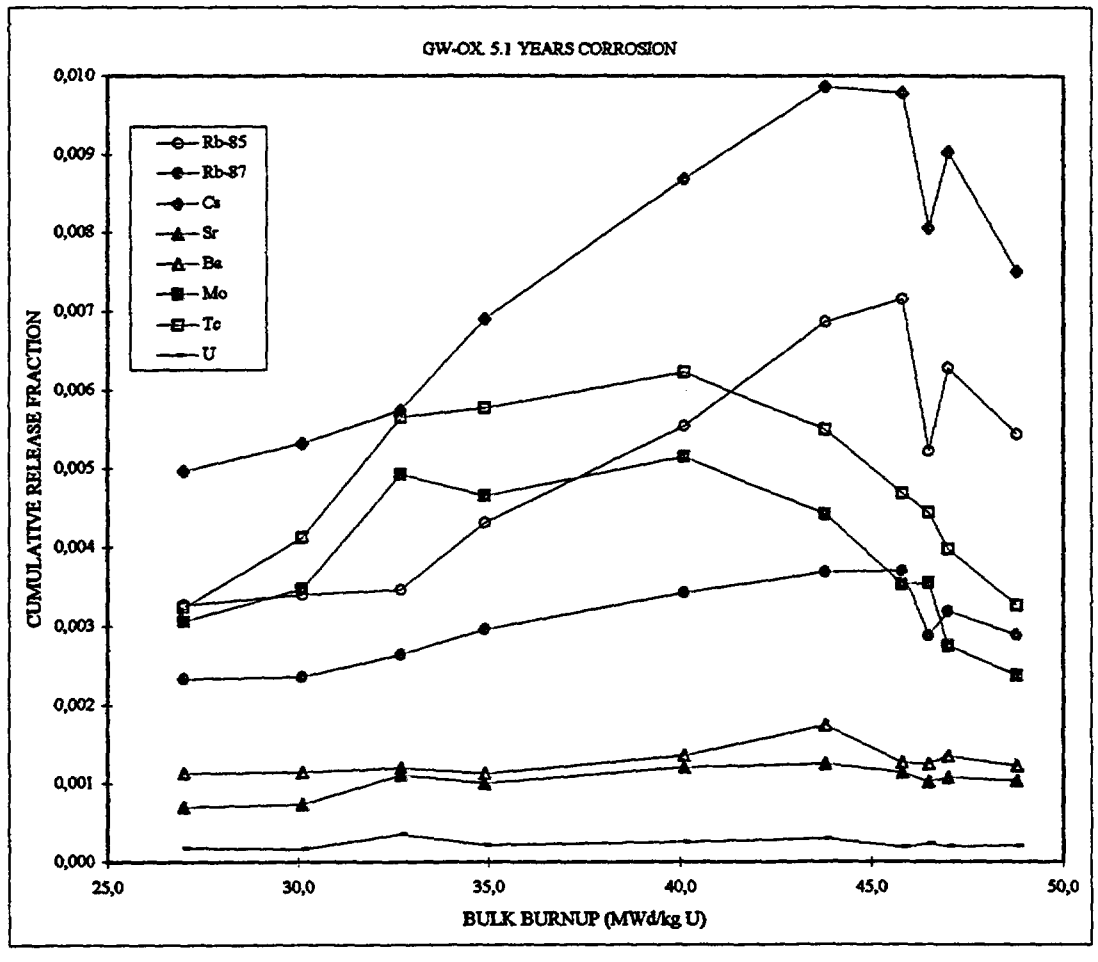


Figure 6-1. Series 11 corrosion tests: Cumulated release fractions in the centrifugates from the 10 GW-OX corrosion tests (9 contact periods: Total corrosion time 5.09 years)

Inspection of the figure leads to a number of comments:

a) For four fission products, Cs, Rb, Mo and Tc, the observed increase, at least initially, of the cumulative release fraction with increased fuel temperature and/or burnup supports the generally held view that these fission products are mobile in the fuel during irradiation.

b) Rather unexpectedly, however, their cumulative release fractions are seen to decrease for corrosion tests on the fuel specimens with the highest burnups. The decreases are largest for Mo and Tc, where the cumulative release fractions for the 48.8 MWd/kg U fuel were lower than for the 27.0 MWd/kg U fuel. The burnup values corresponding to the maximum cumulative release fractions were about 40 and 45 MWd/kg U for Mo/Tc and Cs/Rb respectively.

c) The highest cumulative release fractions observed were those for Cs with values of almost 0.01, in good agreement with the measured integral fission gas release (0.011) for the fuel rod.

d) The curve for Rb-87 is considered to represent the enhanced release behaviour due to migration to grain boundaries during irradiation and selective dissolution during the corrosion tests. As discussed earlier in this report, the Rb-85 curve contains a component, corresponding to a cumulative release fraction of 0.002-

0.003, due to deposition of Rb-85 on fuel and clad surfaces during decay of the fission gas Kr-85 in the rod free volume prior to sampling, and its subsequent dissolution.

e) The results for Sr and Ba show no clear trend with regard to possible correlation between cumulative release fraction and linear heat rating/burnup.
f) The cumulative release fractions for all the six fission products were higher than the values for uranium, which were presumably subject to solubility limitations during each individual contact period.
g) These comments, of course, relate strictly only to centrifugate samples, but are not affected significantly by considerations of the fission product and uranium contents of membrane filter specimens and vessel strip solutions.

In the Series 11 experimental series, three fuel specimens with bulk burnups of 21.2, 36.7 and 49.0 MWd/kg U were subjected to an extensive programme of post-irradiation examinations, including detailed characterisation of the fuel structure by scanning electron microscopy /4-1/. The results from these investigations were discussed fully in section 4 of this report, where it was pointed out that steep radial gradients of both burnup and alpha activity in the pellets indicated that the pellet rim, where these reached maximum levels, could be a favoured site for oxidative corrosion driven by alpha radiolysis. Further, effects related to higher burnups such as the development of a narrow band of higher porosity at the fuel pellet periphery, and to the formation of populations of small (sub-micron) particles of recrystallised UO_2 which decorate grain and pore surfaces in a much wider peripheral zone, could also be important factors.

In the fuel characterisation specimen with a bulk burnup of 36.7 MWd/kg U, particles of recrystallised UO_2 were seen at and near the pellet periphery, but no zone with high porosity was observed. In the specimen with a bulk burnup of 49.0 MWd/kg U, a narrow zone of high porosity, about 20 microns wide, had formed, and recrystallised UO_2 particles were observed in a zone extending over 200 microns into the pellet from the rim. Thus, in the fuel specimens in the Series 11 corrosion tests, these structural effects at the pellet rim develop successively over the burnup range 36.7 to 49.0 MWd/kg U, and if they, together with the high alpha activity level at the pellet rim, cause enhanced corrosion of the fuel, this would be expected to be seen as an increase in cumulative release fraction with burnup for the six specimens with the highest burnups in Figure 6-1, instead of the patterns of decrease noted above.

The most probable explanation for the observed effects is that burnup-related structural changes in the fuel at these levels of burnup reduce the surface area accessible to attack by the corrodant water during the corrosion tests. In section 4 of this report it was shown that differences in fuel swelling (a burnup-related effect) reduced the free volume in the fuel/clad segments over the burnup range of the Series 11 fuel specimens. However, the decrease in available water/fuel contact area postulated here as the cause of the lower cumulative release fractions is thought more likely to occur as changes in the interconnected network of grain boundaries and porosity. Thus although the zone of small pores at the pellet periphery represents, in principle, a population of potential corrosion sites with a high absorption of alpha particle energy in pockets of water, in practice, the pores may

be closed after reactor shut-down and therefore inaccessible for water ingress during subsequent corrosion.

Similarly, the small grains of recrystallised UO_2 can be regarded as potential sites for selective oxidative attack, or as possible nucleation sites for uranium precipitation from saturated corrodant solutions in the grain boundaries, with increased impedance to water ingress as a consequence. Currently there is no direct experimental evidence favouring either mechanism, but the observed decreases in cumulative release fraction shown in Figure 6-1 represent indirect support for the latter.

The amount of uranium in a fuel specimen which could have been deposited in the micro-cracks and grain boundaries due to uranium saturation in the corrodant solution can be estimated if it is assumed that it is identical with the uranium "deficit" represented by the difference in the measured release fractions for U and a suitable monitor of matrix corrosion. The problems associated with the selection of a nuclide suitable as a monitor of fuel matrix dissolution, with particular reference to the possible use of Sr-90, were discussed in the Introduction. It had been hoped, with the commissioning of the ICP-MS instrument, and the possibility it offered for the analysis of fission product Ba-138, that if good agreement was found between the release fraction results measured by means of the Sr-88 and -90 isotopes, and Ba-138, this would strongly support the view of these isotopes as reliable monitors of matrix corrosion.

Inspection of Figure 6-1 shows that, although the cumulative release fractions for Sr and Ba are of similar size, they cannot be regarded as being in particularly good agreement. Further, as will be shown later in this report, there is a significant difference between the release behaviours of Sr and Ba during the early contact periods under GW-OX conditions, and although some of these apparent dissimilarities may be due to the poorer quality of the Ba data (problematic background correction procedure), it can not be assumed that both Sr and Ba are evenly dispersed in the fuel, and are released congruently with matrix dissolution.

However, some added support for the use of Sr isotopes as monitors has been found on comparison of the ICP-MS release fraction results for Sr-88 and Sr-90. It has been suggested that Sr-90 can be enriched at grain boundaries by migration of its short-lived Kr and Rb precursors. This would apply even more to Sr-88, but since the release fractions calculated from Sr-88 measurements only show a slight bias (about 5%) with respect to the corresponding Sr-90 results for later contact periods, this hypothesis appears unlikely.

The Sr cumulative release fractions presented in Figure 6-1, therefore, have been fairly arbitrarily assumed to represent the total amount of dissolved uranium, and the differences between the Sr and U release fractions for each contact period are regarded as the amounts of U lost from solution, and deposited on the internal fuel surfaces. In Figures 6-2 and 6-3 are presented the calculated uranium deposition rates for the nine contact periods for the GW-OX and GW-ANOX specimens respectively. The corresponding results for corrosion tests performed in DW during at least part of their corrosion test programme are not presented since they are complicated by low pH contact periods and changes of corrodant.

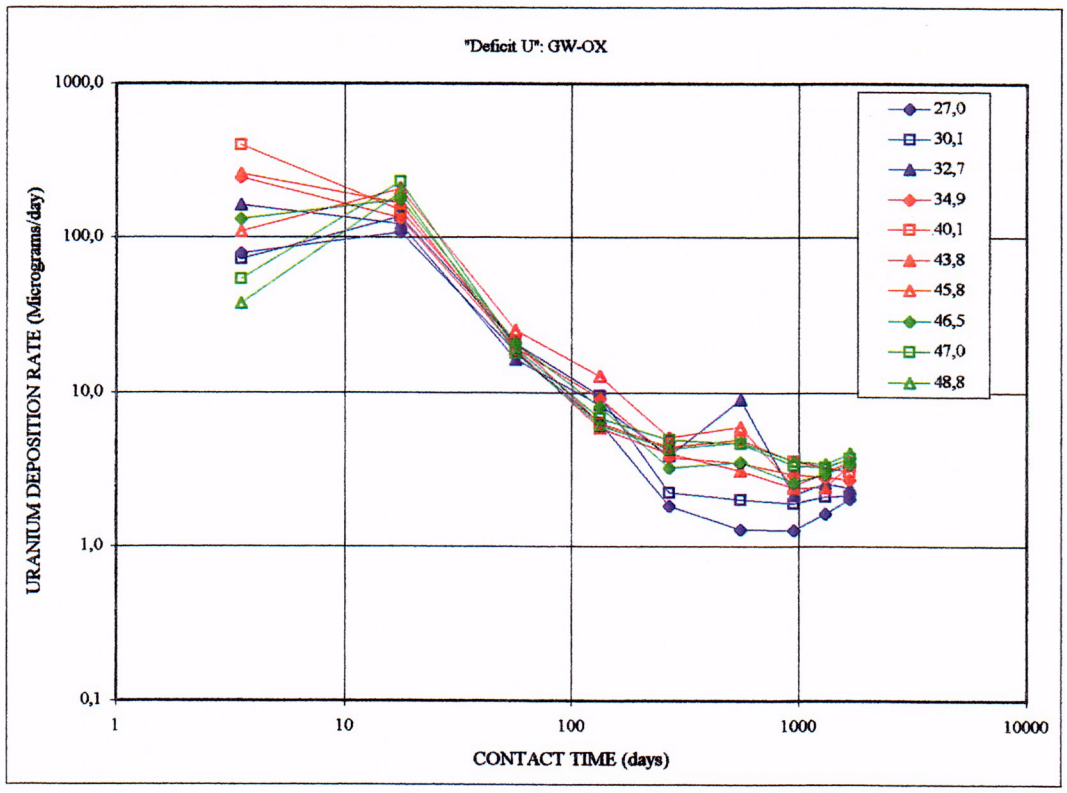


Figure 6-2. *Series 11 GW-OX corrosion tests. Uranium deposition rate over the first nine contact periods. (Based on calculated U "deficits". See text)*

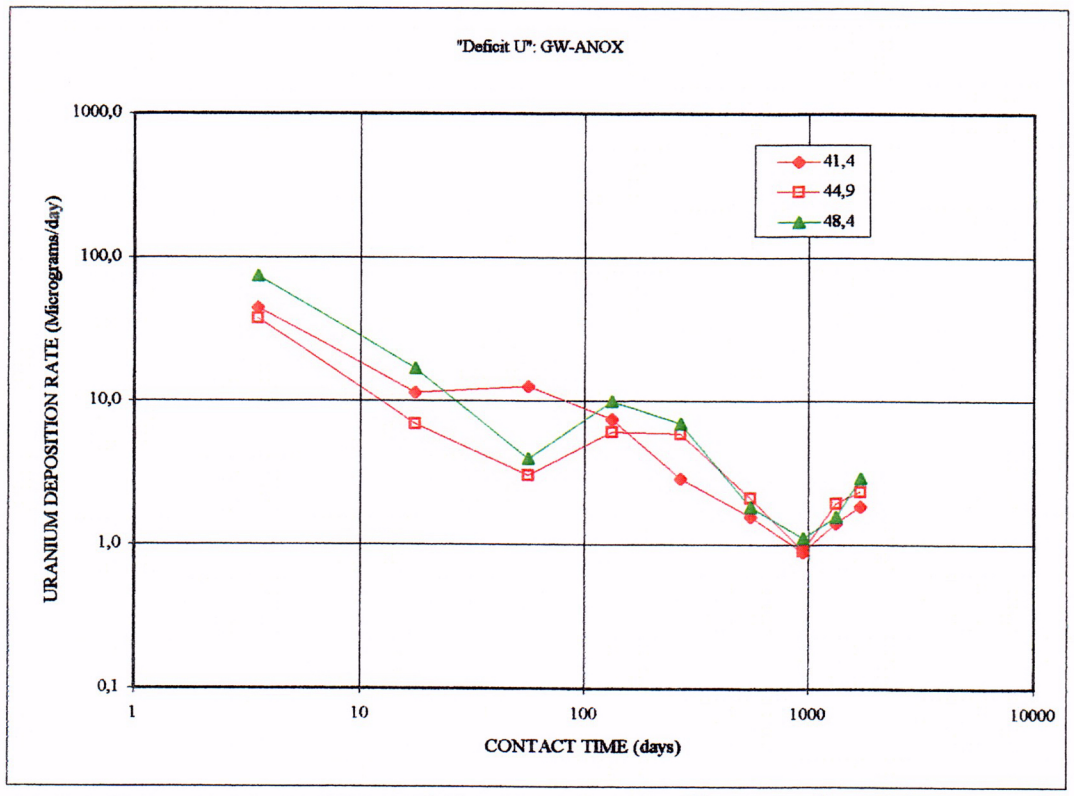


Figure 6-3. *Series 11 GW-ANOX corrosion tests. Uranium deposition rate over the first nine contact periods. (Based on calculated U "deficits". See text)*

C05

The calculated total weights of the uranium deficits (or deposited uranium) for the nine contact periods are presented in Table 6-1, where they are compared with the analytically measured uranium contents of the corresponding centrifugate, membrane filter and vessel strip specimens. Much of the observed variation in the weights of the U deficits depends on uranium inventory weight variations.

Table 6-1. Comparison of the total uranium weights in the three analysed fractions in the corrosion tests with the calculated uranium deficit weights.

			TOTAL URANIUM WEIGHT (Micrograms)			
SPECIMEN	BURNUP	CORRODANT	CENTR	FILTER	STRIP	DEFICIT
11-1	27.0	GW-OX	2313	98	989	7245
11-2	30.1	GW-OX	2473	107	534	9034
11-3	32.7	GW-OX	5144	189	1005	12221
11-4	34.9	GW-OX	2858	128	623	11738
11-5	40.1	GW-OX	3537	145	2191	14320
11-8	43.8	GW-OX	3392	125	318	12010
11-10	45.8	GW-OX	2505	167	621	14589
11-11	46.5	GW-OX	3105	184	961	12187
11-12	47.0	GW-OX	2758	227	1621	13647
11-16	48.8	GW-OX	2901	149	316	13039
11-6	41.4	GW-ANOX	60	6	309	4738
11-9	44.9	GW-ANOX	300	32	1536	5007
11-15	48.4	GW-ANOX	204	23	1983	6182

It was postulated in section 5 of this report that much of the uranium found in the membrane filter and vessel strip specimens was due to fuel fines. Inspection of the table shows that, even if that was not the case, the calculated uranium deficit is much larger than the sum of all the fractions analysed, including the centrifugates.

Returning now to Figure 6-2, it will be shown later in this report that the steep decrease in the (so far hypothetical) uranium deposition rate after the first few weeks of water contact, and the levelling out after longer contact times are similar to the curves of release rate of strontium and other fission products as a function of water contact time, which suggests a causal relationship. This is also the case for the GW-ANOX results which are presented in Figure 6-3.

Obviously, this concept of successively reduced access to fuel internal surfaces must be confirmed by detailed examination of corroded spent fuel, and by specially designed re-dissolution tests.

The cumulative release fractions for centrifugates from other corrosion test series are compared in Tables 6-2 and 6-3 with values for the Series 11 tests which have been discussed in detail above. The comparison must be limited to only a few nuclides, since ICP-MS data is not available for most of the older contact periods.

For corrosion tests under GW-OX conditions, which are presented in Table 6-2, the results for 4 specimens from the Series 7 tests on PWR fuel are compared with the results for specimens 11-5 and 11-8, which have similar burnup values. The

Series 3 corrosion tests on fuel specimens 3-1, 3-2 and 3-3 were unfortunately perturbed by some contact periods with inadvertent low pH, (See Table A-1 in Appendix A) and, therefore, the cumulative release fractions presented in Table 6-2 refer only to the periods with "normal" pH. For comparison with these fuel/clad segment specimens, the cumulative release fractions for corrosion under oxic conditions of specimen 3-24, which consisted of a single fuel fragment of the same BWR reference fuel, with a weight of 0.9891 g in contact with 200 cm^3 of the simulated bicarbonate groundwater, are also included in the table.

Table 6-2. Comparison of cumulative release fractions for corrosion tests on specimens of different fuel, but with similar burnups. (GW-OX conditions)

CUMULATIVE RELEASE FRACTIONS (CENTRIFUGATES)

CORROSION TEST	CONTACT TIME (d)	BURNUP (MWd/kgU)	Cs	Sr	Tc	U
7-3	688	43.0	8,95 E-03	7,66 E-04	8,05 E-04	6,74 E-05
11-5	1861	40.1	8,69 E-03	1,21 E-03	6,23 E-03	2,56 E-04
11-8	1861	43.8	9,86 E-03	1,25 E-03	5,50 E-03	2,95 E-04
7-4	2960	43.0	8,42 E-03	1,01 E-03	5,07 E-03	1,88 E-04
7-5	2960	43.0	1,03 E-02	1,17 E-03	5,42 E-03	2,41 E-04
7-6	2961	43.0	9,51 E-03	1,03 E-03	5,88 E-03	1,68 E-04
3-2*	3800	42.0	1,12 E-02	1,28 E-03		3,47 E-04
3-3*	3974	42.0	1,43 E-02	2,05 E-03		6,37 E-04
3-24**	2460	42.0	1,30 E-02	3,33 E-03	5,11 E-03	1,75 E-03

* Only contact periods with "normal" pH ** Fuel fragment

When it is recalled that the cumulative release fractions for uranium are also dependent on the number of water contact periods, it can be seen that the cumulative release fractions for the fuel/clad segments presented in the table show satisfactory agreement. The 3-3 corrosion test results, however, are the exceptions in this case. The results for Sr and U for the 3-24 corrosion tests are significantly higher than the results for fuel/clad segments, reflecting the higher water/fuel ratio in tests with fuel fragments. (Higher by a factor of about 15)

Table 6-3. Comparison of cumulative release fractions for corrosion tests on specimens of different fuel, but with similar burnups. (GW-ANOX conditions)

CUMULATIVE RELEASE FRACTIONS (CENTRIFUGATES)

CORROSION TEST	CONTACT TIME (d)	BURNUP (MWd/kgU)	Cs	Sr	Tc	U
7-7	688	43.0	9,04 E-03	5,14E-04	4,55 E-04	2,40 E-05
7-8	938	43.0	9,37 E-03	3,94 E-04	3,69 E-04	1,47 E-05
7-9	938	43.0	1,07 E-02	4,75 E-04	1,48 E-04	1,08 E-05
7-10	1807	43.0	1,03 E-02	4,46 E-04	8,44 E-05	9,03 E-06
11-6	1895	41.4	7,44 E-03	3,16 E-04	2,73 E-05	4,11 E-06
11-9	1896	44.9	7,95 E-03	3,44 E-04	2,13 E-05	1,82 E-05
11-15	1897	48.4	1,01 E-02	4,00 E-04	4,56 E-05	1,57 E-05
7-11	2974	43.0	9,62 E-03	5,83 E-04	3,01 E-04	1,13 E-05
7-12	2974	43.0	7,58 E-03	4,56 E-04	1,54 E-04	3,89 E-05

The corrosion tests which are compared in Table 6-3, were all nominally performed in the simulated bicarbonate groundwater under anoxic conditions, but the methods for imposing the anoxic conditions on the groundwater differed between the 7 and 11 experimental series /1-1/. In the Series 7 tests, the groundwater had been circulated over crushed bore-hole rock for several months before being transferred to the corrosion test vessel, while in the Series 11 tests, anoxic conditions were maintained by flowing H_2/Ar over the surface of the corrodant.

In spite of these differences, it is seen that the cumulative release fractions show fairly small scatter.

6.2 ACTINIDES AND LANTHANIDES

In section 6-1 above, the cumulative release fractions for uranium were compared with the corresponding values for selected fission products, all of which had higher values of cumulative release fraction, partly because uranium release in each contact period is limited by solubility considerations, and partly because of selective dissolution.

Here, the uranium cumulative release fractions are compared with those of the actinides and lanthanides, which are all assumed to be homogeneously dispersed in the fuel matrix, but which are also assumed to be solubility limited when released by dissolution of the UO_2. The values for the Series 11 corrosion tests are shown in Table 6-4, together with values for strontium for comparison purposes.

Table 6-4. Series 11 corrosion tests: Comparison of cumulative release fractions of actinides and rare earths with uranium and strontium.

CUMULATIVE RELEASE FRACTIONS (9 Contact periods): GW-OX Conditions

EXPT	Sr	U	Np	Pu	Cm	La	Pr	Nd
11.1	6,97E-04	1,78E-04	4,94E-05	1,25E-05	(8,98E-08)	3,27E-06	(8,02E-07)	2,34E-06
11.2	7,32E-04	1,65E-04	3,70E-05	1,08E-05	(8,38E-07)	5,22E-06	3,17E-06	4,28E-06
11.3	1,11E-03	3,50E-04	9,92E-05	2,60E-05	1,81E-05	8,22E-05	5,54E-05	6,99E-05
11.4	1,00E-03	2,11E-04	3,99E-05	8,99E-06	2,35E-06	1,04E-05	6,72E-06	9,89E-06
11.5	1,21E-03	2,56E-04	4,18E-05	9,97E-06	2,60E-06	1,49E-05	7,77E-06	1,18E-05
11.8	1,25E-03	2,95E-04	4,67E-05	7,71E-06	2,50E-06	1,30E-05	8,03E-06	1,17E-05
11.10	1,14E-03	1,85E-04	5,61E-05	1,00E-05	3,98E-06	1,61E-05	1,12E-05	1,44E-05
11.11	1,02E-03	2,25E-04	4,33E-05	1,01E-05	4,62E-06	1,58E-05	1,24E-05	1,57E-05
11.12	1,07E-03	1,99E-04	4,88E-05	1,10E-05	2,46E-06	1,15E-05	9,34E-06	1,15E-05
11.16	1,04E-03	2,05E-04	4,21E-05	1,18E-05	2,11E-06	8,89E-06	7,07E-06	8,81E-06

CUMULATIVE RELEASE FRACTIONS (9 Contact periods): GW-ANOX Conditions

EXPT	Sr	U	Np	Pu	Cm	La	Pr	Nd
11.6	3,16E-04	4,11E-06	7,92E-07	(1,73E-07)	(1,63E-07)	2,34E-06	6,40E-07	7,10E-07
11.9	3,44E-04	1,82E-05	1,21E-06	(1,32E-07)	(4,35E-07)	2,86E-06	1,29E-06	1,04E-06
11.15	4,00E-04	1,57E-05	(1,25E-06)	3,06E-07	(1,11E-06)	6,75E-06	3,46E-06	3,03E-06

The values given in parentheses are for specimens for which values of release fraction for 3 or more individual contact periods are not available for summation.

Results for corrosion tests performed in the simulated bicarbonate groundwater under both oxic and anoxic conditions are presented. In the compilation of release fractions in Appendix B, results such as "less than", or "Not detected" have been registered as zero, and, as a consequence, some sets of release fractions for an individual fuel specimen are incomplete but have been summated. In such cases, the cumulative release fraction has been calculated, but when 3 or more individual results are not available, the value is reported in parentheses in Table 6-4.

The ratios of the cumulated release fraction values in the centrifugates in Table 6-4 to the corresponding values for uranium are given in Table 6-5.

Table 6-5. Series 11 corrosion tests: Cumulative release fractions in Table 6-4: Ratios to uranium cumulative release fractions.

RATIOS OF CUMULATIVE RELEASE FRACTIONS (9 Contact periods): GW-OX Conditions

EXPT	Sr	U	Np	Pu	Cm	La	Pr	Nd
11.1	3,92	1,0	0,278	0,070	(0,0005)	0,018	(0,005)	0,013
11.2	4,44	1,0	0,224	0,066	(0,005)	0,032	0,019	0,026
11.3	3,17	1,0	0,284	0,074	0,052	0,235	0,158	0,200
11.4	4,75	1,0	0,189	0,043	0,011	0,049	0,032	0,047
11.5	4,73	1,0	0,163	0,039	0,010	0,058	0,030	0,046
11.8	4,23	1,0	0,158	0,026	0,008	0,044	0,027	0,040
11.10	6,15	1,0	0,303	0,054	0,022	0,087	0,060	0,077
11.11	4,54	1,0	0,192	0,045	0,021	0,070	0,055	0,070
11.12	5,39	1,0	0,245	0,055	0,012	0,058	0,047	0,058
11.16	5,05	1,0	0,205	0,057	0,010	0,043	0,034	0,043

RATIOS OF CUMULATIVE RELEASE FRACTIONS (9 Contact periods): GW-ANOX Conditions

EXPT	Sr	U	Np	Pu	Cm	La	Pr	Nd
11.6	76,8	1,0	0,193,	(0,042)	(0,040)	0,569	0,155	0,173
11.9	18,9	1,0	0,067	(0,007)	(0,024)	0,157	0,071	0,057
11.15	25,6	1,0	(0,080)	0,020	(0,071)	0,431	0,221	0,193

The values given in the table refer to the cumulated release fractions for all the nine contact periods for which analytical data is available.

In section 3 of this report, the relatively poor reliability of the actinide and lanthanide analytical data, particularly with respect to the necessarily somewhat arbitrary background correction procedures, has been discussed in detail. The scatter in the data reported in the tables, therefore, is not unexpected. In spite of this, however, general trends can be clearly seen. (The anomalous results for specimen 11-3 represent an exception; during the 6th contact period this specimen experienced an unexplained increase in corrosion rate which in some respects has persisted during later contact periods. This will be discussed later in the report.)

Thus, it is obvious that in the centrifugates, there are "deficits" relative to uranium of both actinides and lanthanides. Since these deficits are relatively large, they can not be explained by "losses" to the membrane filter and vessel strip fractions, and the tentative conclusion in section 5, that the actinide and lanthanide contents of these fractions are due to fuel fines, is still valid.

The apparent plutonium deficit was observed shortly after the start of the corrosion programme in 1982, as was the marked decrease in Pu concentration in the centrifugates when contact period durations were lengthened after the first few contacts. This effect has been reviewed previously /6-1/ and will not be considered further here.

Inspection of the data in Tables 6-4 and 6-5 suggests that, if the "deficit" actinides and lanthanides are co-precipitated with or scavenged by the deposited uranium deficit, they would be enriched in the deposit with respect to uranium. An attempt to confirm this enrichment effect was performed several years ago when small traces of dehydrated schoepite scraped from a fuel specimen corroded in deionised water were dissolved and analysed /6-2/. The evaluation of the measurements was complicated by contamination of the sample with traces of fuel, but no convincing evidence of actinide enrichment was observed. Clearly, it would be useful if this type of experiment could be repeated under more favourable circumstances.

When evaluating the results of the retroactive ICP-MS analytical campaign, /1-3/, it was observed that substantial losses of plutonium and curium had occurred in archive solutions which had been stored for long times. Because of this effect, the values of release fractions for these elements in early contact time specimens listed in Appendix B, have been based largely on the results of radioactivity measurements. The values given in Tables 6-4 and 6-5 for Np, La, Pr and Nd, however, are the results of ICP-MS analysis and can, therefore, be too low because of storage losses.

The ICP-MS results for the later contact periods (6-9) in the Series 11 tests were obtained shortly after sampling, however, and are expected to be more reliable. The average values of the centrifugate molarities of these four contact periods, are presented in Table 6-6, where they can be compared with the values for the latest contact periods in the Series 3 and 7 corrosion tests.

Table 6-6. Comparison of actinide and lanthanide molarities: average of latest contact times for tests under GW-OX conditions.

Moles/dm^3

Specimen	BURNUP	U	Np	Pu	Cm	La	Nd
11-1	27.0	7,00E-06	3,15E-10	8,02E-10	(1,03E-13)	1,47E-10	4,57E-10
11-2	30.1	7,81E-06	4,03E-10	6,32E-10	5,82E-13	3,64E-10	9,15E-10
11-3	32.7	2,23E-05	2,61E-09	1,16E-08	1,76E-11	1,27E-08	4,61E-08
11-4	34.9	1,00E-05	6,12E-10	6,06E-10	8,98E-13	6,15E-10	1,66E-09
11-5	40.1	1,17E-05	9,47E-10	8,37E-10	1,41E-12	7,25E-10	1,84E-09
11-8	43.8	1,22E-05	1,13E-09	8,39E-10	2,39E-12	5,87E-10	2,08E-09
11-10	45.8	8,91E-06	1,41E-09	1,14E-09	4,04E-12	5,80E-10	3,12E-09
11-11	46.5	9,93E-06	1,21E-09	1,37E-09	2,93E-12	5,21E-10	1,76E-09
11-12	47.0	8,97E-06	1,20E-09	1,40E-09	4,38E-12	6,00E-10	2,59E-09
11-16	48.8	9,03E-06	1,17E-09	2,01E-09	2,50E-12	3,37E-10	1,85E-09
3-2	42.0	1,51E-05	1,97E-09	5,01E-10	3,79E-13	1,09E-09	1,50E-09
3-3	42.0	2,96E-05	1,63E-09	8,36E-10	6,36E-12	3,05E-09	6,99E-09
7 Mean	43.0	1,32E-05	3,77E-09	1,57E-09	2,15E-12	7,71E-10	1,81E-09

The molarity results for the Series 11 corrosion tests, again excluding the results for fuel specimen 11-3, show a range of scatter which could well be due to the arbitrary or uncertain background correction procedures which have been discussed above. Thus, it is difficult to decide unambiguously whether or not solubility limits have been reached for any element. Comparison with the results for the average of the Series 7 corrosion tests, and, in particular, the observation of the difference in the results from specimens 3-2 and 3-3, suggest that saturation has not been reached.

6.3 LOW pH DISSOLUTION / REDISSOLUTION EFFECTS

In the preceding sections, it has been postulated that during the first few years of corrosion in bicarbonate groundwaters and deionised water of fuel/clad segments, there is a continuous formation on the fuel surfaces, possibly preferentially in the interconnecting network of porosity and grain boundaries, of deposits, which contain mainly uranium, actinides and lanthanides. From the available analytical results on the three sample fractions in the corrosion tests, centrifugates, membrane filters and vessel strip solutions, it can be deduced that the actinides and lanthanides are present in the deposit in higher concentrations than in the spent fuel itself.

An unsuccessful attempt to confirm such enrichment by analysis of a precipitate of schoepite found on a PWR fuel specimen corroded in deionised water was mentioned above. However, during the corrosion programme, some fuel specimens have been subjected to low pH contact with various corrodants either inadvertently by contamination, or by planned contact periods. Also, some specimens have experienced changes of corrodant or redox conditions during the sequential corrosion tests, again, either inadvertently or by design. The results of such contact periods can be of interest in the context of possible redissolution of the precipitates mentioned above, and will be considered briefly here.

The centrifugate fractional release rates for all contact periods performed at lower than normal pH are listed in Table 6-7. They include the results of tests made over 10 years ago /2-1/ on fuel/clad segments of the BWR reference fuel, (Series 3.4 and 3.5), which were contacted for about 20 or 91 days with pH-adjusted corrodant solutions, using HCl for adjustment, after long cumulated contact times at the normal pH. The other results refer to tests where the normal corrodant had been inadvertently contaminated by the HNO_3/HF solution used for vessel stripping in the hot-cell. The ratios of the release rates to the corresponding uranium values are tabulated in Table 6-8.

The release fractions for the 6th contact period under GW-OX conditions for fuel specimen 11-3 were appreciably larger than the values for its 9 sibling specimens, and enhanced release fractions for some nuclides were also observed for the subsequent contact periods. The release fractions for the 11-3 corrosion test are compared with those for specimen 11-4 in Table 6-9. Finally, the release fractions for the 3 Series 11 corrosion tests which were corroded first in deionised water, and then in groundwater under anoxic conditions are presented in Table 6-10.

Table 6-7. Low pH contact periods: Fractional release rates. (centrifugates)

COTI: Contact time (days) — FRACTIONAL RELEASE RATE (/d)

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	Ce	Eu	Nd
3.4.7.2	GW-OX	2,00	20			1,86E-05	2,51E-05				2,47E-05		7,60E-06	3,18E-05	3,22E-05	2,57E-05	
3.2.5	GW-OX	2,30	91			1,56E-05	1,37E-05				1,13E-05		1,28E-06	6,71E-06	7,99E-06	8,26E-06	
3.5.8.3	GW-OX	3,40	20			1,23E-05	1,32E-05				1,02E-05		1,24E-06	7,95E-06	2,52E-06	3,33E-06	
3.5.8.91	GW-OX	3,65	91			9,08E-06	8,47E-06				4,31E-06		4,90E-08	3,77E-06	1,18E-06	1,46E-06	
3.4.8.3	GW-OX	3,70	23			1,24E-05	1,54E-05				1,93E-05		1,35E-06	6,40E-06	7,50E-06	7,70E-06	
3.5.7.2	GW-OX	4,10	22			6,50E-06	1,02E-05				3,92E-06		4,95E-06	4,29E-06	7,45E-06	7,64E-06	
3.3.9	GW-OX	4,20	218			1,56E-06	8,26E-07				4,71E-07		3,38E-07	1,31E-06	1,61E-06	1,18E-06	
3.2.9	GW-OX	4,25	218			2,68E-06	1,43E-06				3,53E-07		7,02E-07	1,84E-06	1,72E-06	1,44E-06	
3.4.8.91	GW-OX	4,30	91			1,70E-05	1,32E-05				7,35E-06			1,70E-06	2,16E-06	2,15E-06	
3.3.5	GW-OX	4,75	91			5,62E-06	3,38E-06				5,34E-07		1,31E-07	6,99E-07	1,46E-06	1,13E-06	
3.4.6.3	GW-OX	4,90	20			7,60E-06	9,20E-06				7,45E-06		1,65E-06	6,85E-06	1,22E-05	9,15E-06	
3.3.10	GW-OX	5,10	174			3,03E-06	1,77E-06				1,57E-06		1,83E-08	4,30E-08	3,71E-08	6,61E-08	
3.5.6.3	GW-OX	5,50	20			6,60E-06	9,65E-06				4,20E-07		1,46E-06	2,87E-06	2,94E-06	3,11E-06	
3.2.10	GW-OX	6,60	174			2,63E-06	6,04E-07				2,41E-08		3,83E-09	3,07E-09		8,16E-09	

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La/Ce	Pr/Eu	Nd
11.14.4	DW-OX	3,64	91	5,33E-06	4,31E-06	6,13E-06	3,02E-06	6,62E-06	3,63E-07	6,29E-07	1,21E-06	1,47E-06	1,32E-06	6,34E-07	7,46E-07	7,71E-07	8,10E-07
11.7.4	DW-OX	3,80	91	1,91E-06	1,90E-06	1,66E-06	1,20E-06	1,66E-06	2,91E-07	5,33E-07	1,19E-06	1,01E-06	9,35E-07	4,68E-07	2,09E-07	1,97E-07	2,30E-07
3.1.9	DW-OX	3,85	218			3,08E-06	1,71E-06				1,86E-06		2,23E-07	9,36E-07	8,30E-07	1,22E-06	
3.1.5	DW-OX	3,90	91			6,24E-06	4,10E-06				3,44E-06		1,48E-07	1,79E-07	3,44E-07	1,96E-07	
3.1.10	DW-OX	5,20	174			3,76E-06	3,21E-06				2,06E-06			1,13E-06	1,52E-06	1,39E-06	
11.13.4	DW-ANX	4,67	91	6,02E-07	5,92E-07	7,82E-07	8,47E-08	2,07E-07	1,02E-07	1,57E-08	1,64E-07	1,10E-07	6,80E-09		6,95E-11	2,60E-10	6,32E-10

Table 6-8. Low pH contact periods: Fractional release rates. (centrifugates): Ratios to uranium.

RATIO TO URANIUM

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	Ce	Eu	Nd
3.4.7.2	GW-OX	2,00	20			0,75	1,02				1,00		0,31	1,29	1,31	1,04	
3.2.5	GW-OX	2,30	91			1,38	1,22				1,00		0,11	0,59	0,71	0,73	
3.5.8.3	GW-OX	3,40	20			1,21	1,30				1,00		0,12	0,78	0,25	0,33	
3.5.8.91	GW-OX	3,65	91			2,11	1,97				1,00		0,01	0,88	0,27	0,34	
3.4.8.3	GW-OX	3,70	23			0,64	0,80				1,00		0,07	0,33	0,39	0,40	
3.5.7.2	GW-OX	4,10	22			1,66	2,61				1,00		1,26	1,09	1,90	1,95	
3.3.9	GW-OX	4,20	218			3,32	1,75				1,00		0,72	2,78	3,41	2,51	
3.2.9	GW-OX	4,25	218			7,59	4,06				1,00		1,99	5,21	4,86	4,08	
3.4.8.91	GW-OX	4,30	91			2,32	1,79				1,00			0,23	0,29	0,29	
3.3.5	GW-OX	4,75	91			10,52	6,32				1,00		0,24	1,31	2,73	2,12	
3.4.6.3	GW-OX	4,90	20			1,02	1,23				1,00		0,22	0,92	1,64	1,23	
3.3.10	GW-OX	5,10	174			1,92	1,12				1,00		0,01	0,03	0,02	0,04	
3.5.6.3	GW-OX	5,50	20			15,73	23,00				1,00		3,47	6,83	7,01	7,40	
3.2.10	GW-OX	6,60	174			109,02	25,05				1,00		0,16	0,13		0,34	

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La/Ce	Pr/Eu	Nd
11.14.4	DW-OX	3,64	91	4,40	3,56	5,05	2,49	5,46	0,30	0,52	1,00	1,21	1,09	0,52	0,62	0,64	0,67
11.7.4	DW-OX	3,80	91	1,61	1,60	1,39	1,01	1,40	0,24	0,45	1,00	0,85	0,79	0,39	0,18	0,17	0,19
3.1.9	DW-OX	3,85	218			1,66	0,92				1,00		0,12	0,50	0,45	0,66	
3.1.5	DW-OX	3,90	91			1,81	1,19				1,00		0,04	0,05	0,10	0,06	
3.1.10	DW-OX	5,20	174			1,82	1,56				1,00			0,55	0,74	0,67	
11.13.4	DW-ANX	4,67	91	3,67	3,61	4,76	0,52	1,26	0,62	0,10	1,00	0,67	0,04		0,0004	0,002	0,004

Table 6-9. Comparison of release fractions: Specimens 11-3 and 11-4. (GW-OX)

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Pr	Nd
11.3.1	GW-OX	8,32	7	1,40E-03	7,32E-04	3,29E-03	8,41E-05	1,43E-04	3,57E-05	2,90E-05	1,35E-05	3,42E-06	2,61E-06		1,88E-07		
11.3.2	GW-OX	8,32	21	3,33E-04	2,64E-04	5,21E-04	1,71E-04	3,58E-04	1,06E-05	1,18E-05	1,20E-05	1,13E-06	2,69E-06	5,75E-07	2,24E-06	1,55E-06	2,08E-06
11.3.3	GW-OX	8,40	63	1,38E-04	1,20E-04	8,80E-05	7,13E-05	2,09E-04	4,20E-05	1,23E-04	7,57E-06	2,78E-07	8,15E-07	2,33E-07	1,62E-06	7,63E-07	9,07E-07
11.3.4	GW-OX	8,35	91	1,72E-04	1,52E-04	1,39E-04	7,48E-05	1,32E-04	6,15E-05	3,13E-04	2,75E-05	2,99E-06	1,27E-06		1,02E-06	8,28E-07	1,08E-06
11.3.5	GW-OX	8,49	182	1,87E-04	1,74E-04	2,01E-04	5,57E-05	8,07E-05	2,31E-04	8,39E-04	1,12E-05	1,69E-06	3,50E-07	1,99E-07	6,38E-07	5,59E-07	9,03E-07
11.3.6	GW-OX	8,29	371	5,46E-04	5,35E-04	7,40E-04	3,56E-04	1,56E-04	1,12E-03	1,25E-03	1,48E-04	5,86E-05	1,14E-05	1,29E-05	6,09E-05	3,84E-05	4,97E-05
11.3.7	GW-OX	8,58	413	3,23E-04	3,08E-04	3,77E-04	1,29E-04	5,73E-05	1,65E-03	1,67E-03	7,33E-05	1,89E-05	3,48E-06	2,19E-06	1,15E-05	7,33E-06	8,54E-06
11.3.8	GW-OX	8,41	301	1,80E-04	1,65E-04	2,02E-04	7,17E-05	3,27E-05	8,19E-04	6,56E-04	2,28E-05	5,87E-06	1,93E-06	1,41E-06	5,33E-07	3,91E-06	4,46E-06
11.3.9	GW-OX	8,52	413	1,86E-04	1,88E-04	1,89E-04	9,66E-05	3,07E-05	9,68E-04	7,63E-04	3,45E-05	6,36E-06	1,44E-06	6,39E-07	3,63E-06	2,07E-06	2,24E-06
11.4.1	GW-OX	8,30	7	2,39E-03	1,19E-03	4,88E-03	1,32E-04	2,02E-04	5,33E-05	4,26E-05	1,61E-05	1,26E-05	2,99E-06		8,13E-08		2,55E-08
11.4.2	GW-OX	8,45	21	3,49E-04	2,87E-04	4,92E-04	1,97E-04	3,27E-04	7,17E-06	1,22E-05	8,83E-06	7,93E-07	2,28E-06	7,16E-07	2,46E-06	1,68E-06	2,15E-06
11.4.3	GW-OX	8,45	63	1,69E-04	1,48E-04	1,19E-04	9,27E-05	1,94E-04	4,70E-05	1,40E-04	9,86E-06	6,04E-07	1,16E-06	4,97E-07	1,62E-06	1,53E-06	1,89E-06
11.4.4	GW-OX	8,35	91	2,11E-04	1,89E-04	1,43E-04	8,38E-05	1,68E-04	1,08E-04	5,25E-04	2,71E-05	2,00E-06	1,14E-06	2,30E-07	1,66E-06	1,29E-06	2,35E-06
11.4.5	GW-OX	8,45	182	1,96E-04	1,83E-04	1,79E-04	6,01E-05	1,01E-04	4,19E-04	1,10E-03	1,32E-05	2,39E-06	4,10E-07	2,21E-07	7,53E-07	7,83E-07	1,07E-06
11.4.6	GW-OX	8,34	371	2,62E-04	2,50E-04	3,24E-04	1,12E-04	2,98E-05	1,03E-03	1,29E-03	2,49E-05	2,19E-06	2,38E-07	5,08E-07	1,16E-06	4,38E-07	1,16E-06
11.4.7	GW-OX	8,57	413	3,05E-04	2,90E-04	3,24E-04	1,23E-04	3,40E-05	1,28E-03	1,27E-03	4,08E-05	5,92E-06	2,92E-07	6,76E-08	5,26E-07	3,44E-07	4,50E-07
11.4.8	GW-OX	8,51	301	1,97E-04	1,83E-04	2,06E-04	8,53E-05	2,97E-05	7,36E-04	6,08E-04	2,76E-05	5,79E-06	2,51E-07	6,69E-08	6,10E-07	2,86E-07	3,56E-07
11.4.9	GW-OX	8,53	413	2,35E-04	2,37E-04	2,37E-04	1,19E-04	3,86E-05	9,71E-04	7,89E-04	4,29E-05	7,64E-06	2,25E-07	4,61E-08	1,50E-06	3,66E-07	4,38E-07

Table 6-10. Effect of changing corrodant from deionised water to bicarbonate groundwater.

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Pr	Nd
11.7.1	DW-OX	6,84	7	3,61E-03	1,33E-03	6,10E-03	1,82E-05	1,51E-04	9,21E-06	2,27E-05	9,62E-06	1,28E-05	4,84E-06		1,68E-07		
11.7.2	DW-OX	6,68	22	1,49E-04	1,04E-04	2,42E-04	1,21E-05	7,39E-05	2,35E-05	2,41E-05	2,26E-06	2,41E-05	8,77E-06	1,02E-07	4,16E-07		5,82E-08
11.7.3	GW-OX	8,40	62	2,11E-04	1,97E-04	1,42E-04	2,94E-04	2,92E-04	5,06E-05	2,09E-05	1,99E-05	7,81E-06	3,28E-06	2,21E-07	1,60E-06	8,60E-07	1,12E-06
11.7.4	DW-OX	3,80	91	1,74E-04	1,73E-04	1,51E-04	1,09E-04	1,51E-04	2,65E-05	4,85E-05	1,08E-04	9,23E-05	8,51E-05	4,26E-05	1,90E-05	1,80E-05	2,09E-05
11.7.5	DW-OX	6,67	182	6,32E-05	6,21E-05	3,00E-05	2,28E-06	5,73E-06	1,55E-05	1,81E-05	2,45E-08	2,28E-05	4,30E-06	1,14E-07	4,30E-07	3,33E-07	4,27E-07
11.7.6	DW-OX	7,58	372	1,69E-04	1,67E-04	9,00E-05	1,47E-04	6,04E-05	1,06E-05	9,80E-05	4,89E-09	1,32E-05	2,62E-06	2,61E-06	1,51E-05	5,21E-06	6,60E-06
11.7.7	GW-ANX	9,76	414	6,08E-04	6,05E-04	6,88E-04	6,60E-05	2,69E-07	8,01E-03	1,36E-06	9,24E-05	1,14E-06	1,61E-07	2,04E-07	2,48E-07	1,84E-07	2,38E-07
11.7.8	GW-ANX	9,51	328	1,44E-04	1,36E-04	2,81E-04	8,96E-05	4,02E-06	6,59E-04	2,32E-07	8,44E-06	3,43E-07	9,53E-09		2,43E-07	7,47E-08	1,06E-07
11.7.9	GW-ANX	9,41	420	3,40E-05	3,42E-05	7,96E-05	8,03E-05	7,44E-06	4,40E-05	1,51E-06	3,85E-05	5,76E-07	7,67E-08	2,22E-07	7,36E-07	5,14E-07	5,22E-07

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Pr	Nd
11.14.1	DW-OX	6,72	7	1,85E-03	6,88E-04	3,40E-03	2,88E-05	8,44E-05	5,69E-05	6,59E-05	1,91E-05	1,01E-05	2,45E-06	1,22E-06	3,60E-06	1,54E-06	1,72E-06
11.14.2	DW-OX	6,70	22	2,36E-03	8,52E-04	3,27E-03	2,11E-06	6,58E-06	4,71E-05	2,52E-05	3,06E-06	2,23E-05	7,28E-06		1,89E-08	6,00E-08	7,52E-09
11.14.3	DW-OX	6,33	62	2,92E-04	2,02E-04	3,69E-04	2,64E-05	2,22E-05	6,06E-05	6,65E-05	1,24E-07	7,20E-05	2,27E-05		2,03E-08		3,11E-09
11.14.4	DW-OX	3,64	92	4,85E-04	3,93E-04	5,57E-04	2,75E-04	6,02E-04	3,31E-05	5,72E-05	1,10E-04	1,34E-04	1,20E-04	5,77E-05	6,78E-05	7,02E-05	7,37E-05
11.14.5	DW-OX	6,10	181	3,86E-05	3,88E-05	2,29E-05	9,60E-07	6,07E-06	3,99E-05	2,97E-05	2,40E-09	1,66E-05	3,16E-06		4,17E-08	2,76E-08	2,79E-08
11.14.6	DW-OX	5,90	372	6,86E-05	6,60E-05	5,29E-05	3,63E-05	1,62E-05	2,32E-05	2,15E-05	9,53E-09	1,65E-05	1,60E-06	4,50E-07	1,08E-06	1,61E-07	3,38E-07
11.14.7	GW-ANX	9,66	414	6,64E-04	6,59E-04	2,03E-03	1,29E-04	5,25E-06	7,40E-03	9,51E-07	3,03E-05	8,15E-07	1,17E-07	3,95E-08	2,24E-07	1,24E-07	2,06E-07
11.14.8	GW-ANX	9,04	328	7,65E-05	6,67E-05	2,08E-04	8,95E-05	7,80E-06	1,90E-04	2,60E-07	1,12E-05	5,99E-07	3,47E-08	7,33E-08	7,77E-07	4,26E-07	6,01E-07
11.14.9	GW-ANX	9,21	420	5,39E-05	5,42E-05	1,24E-04	8,93E-05	2,81E-05	1,26E-04	2,58E-06	8,43E-05	2,42E-06	2,13E-07		1,17E-04	6,71E-07	6,01E-07

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	CORR.	pH	COTI	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Pr	Nd
11.13.1	DW-ANX	5,90	7	4,72E-03	1,66E-03	7,62E-03	1,31E-05	5,75E-05	1,30E-05	5,28E-06	4,05E-06	4,37E-07	5,12E-08	6,30E-07	3,25E-07	3,15E-07	4,00E-07
11.13.2	DW-ANX	6,79	21	9,16E-04	3,69E-04	1,75E-03	3,04E-06	3,03E-05	8,06E-06	3,39E-06	8,13E-06	9,39E-07		9,22E-08		5,14E-08	1,31E-08
11.13.3	DW-ANX	5,92	63	6,19E-05	5,90E-05	2,23E-04	4,03E-06	1,35E-05	1,01E-05	7,11E-07	7,88E-06	7,26E-07	2,36E-09	9,47E-08	1,20E-07	1,97E-08	1,25E-07
11.13.4	DW-ANX	4,67	91	5,48E-05	5,39E-05	7,11E-05	7,71E-06	1,88E-05	9,24E-06	1,43E-06	1,49E-05	1,00E-05	6,19E-07		6,33E-09	2,37E-08	5,75E-08
11.13.5	DW-ANX	4,04	181	8,06E-05	7,80E-05	7,66E-05	1,45E-04	1,38E-04	8,94E-06	3,18E-06	1,10E-05	2,19E-06	1,28E-06	6,32E-07	2,34E-07	3,02E-07	3,80E-07
11.13.6	DW-ANX	3,94	370	5,48E-05	5,02E-05	6,40E-05	7,58E-05	8,30E-05	4,57E-06	1,10E-05	1,15E-05	1,23E-06	5,27E-07	4,43E-06	6,45E-06	5,07E-06	4,97E-06
11.13.7	GW-ANX	9,71	414	4,34E-05	3,40E-05	6,19E-05	1,21E-05	1,43E-06	3,28E-04	1,52E-05	7,00E-07	8,58E-07	5,30E-08	1,41E-08	2,28E-07	9,12E-08	1,57E-07
11.13.8	GW-ANX	9,01	328	4,22E-05	3,16E-05	9,20E-05	9,93E-05	7,38E-06	3,32E-04	1,50E-06	2,20E-07	1,02E-07	1,87E-08		3,70E-08	1,92E-08	2,91E-08
11.13.9	GW-ANX	9,22	420	5,11E-05	5,14E-05	7,10E-05	2,21E-05	1,91E-05	1,76E-04	5,51E-06	1,18E-05	1,15E-06	1,46E-07	4,03E-07	9,92E-07	5,28E-07	3,65E-07

Inspection of Tables 6-7 and 6-8 shows that there is no clear relation between the ratios of the release rates of the various components in the centrifugates and the pH of the corrodant solution as measured at the end of the contact period. This is not unexpected since other experimental parameters such as the pH, duration or corrodant type in previous contact periods could also be expected to be of importance. Further, some scatter in the data can be caused by analytical flyers. However, it is clear that, at the most, the composition of the material dissolved during the low pH exposures approaches the composition in the uncorroded fuel, but there is little substantial evidence of re-dissolution of previously deposited actinides.

Because of this experimental inability (so far) to demonstrate the actinide "deficit" effect discussed above, it is reasonable to re-question the validity of the assumption made previously in section 5 of this report that most if not all the uranium (and actinides) found in the membrane filter and vessel strip fractions are due to fuel fines. However, when the total material balances for uranium, the other actinides and lanthanides for all three fractions analysed are studied in detail, it is found that in almost all contact periods, there is a clear deficit of plutonium, neptunium and curium in these tests. Deposition on fuel and clad surfaces is still the most favoured explanation for the effect.

The hitherto unexplained change in the corrosion behaviour of specimen 11-3, which was one of the ten Series 11 tests contacted sequentially with bicarbonate groundwater (GW-OX), is illustrated in Table 6-9, where the centrifugate release fractions for the 9 contact periods are compared with the corresponding values for specimen 11-4. Comparison of the release fractions for the 6th contact period shows that the values for specimen 11-3 were 2-5 times higher for uranium and the "mobile" fission products (Rb, Cs, Sr, Ba) than for specimen 11-4. The increase can be seen very clearly in the release rate plots later in this report, and also in Figure 6-2. The release fractions for the actinides and lanthanides were about one order of magnitude higher.

For uranium and the mobile fission products, the differences had largely disappeared in the 7th contact period. It can be seen, however, that the differences for Pu, Cm and the lanthanides, persist into the 9th contact period. In Appendix B, it can be seen that for the 6th contact period, the 11-3-6 vessel strip solution had uneven but high release fractions, indicating the dissolution of residual fuel fines, corresponding to about 600 micrograms of uranium. Probably, the high release values in the centrifugate sample are due to favourable conditions during the contact period for dissolution of fuel fines at the bottom of the corrosion vessel.

A tentative explanation for the persistence of the effect for Pu, Cm and the lanthanides, even after the change of corrosion vessel after each contact time, can be that the loss of fuel particles (about 2 mg) from the fuel/clad specimen during the 6th contact period, exposed new fuel surfaces to corrosive attack. It will be difficult to confirm this hypothesis, but special attention will be paid to the appearance of the fuel surfaces during post-corrosion examination.

The evaluation of the results from the 3 experiments in the Series 11 tests, (See Table 6-10), which for the first 2 years were corroded in deionised water, was made more complicated by inadvertent changes in the corrosion test schedule. It was originally intended that the tests, two performed under oxic conditions, and one under anoxic conditions, would be concluded by a number of contact periods in the bicarbonate groundwater under anoxic conditions in order to study possible re-dissolution of precipitates by carbonate complexing of uranium. However, as is shown in Table A-4 in Appendix A, the third contact of specimen 11-7 was by mistake performed in the bicarbonate groundwater, and it can also be seen that the deionised water used for all 3 specimens, 11-7, 11-13 and 11-14, during the 4th contact period, had low pH values indicating contamination with traces of the acid solution used for stripping the corrosion vessels. (The results for these latter 3 samples were discussed above.)

Thus, at the time for the changeover from deionised water to bicarbonate groundwater after the 6th contact period, the three fuel specimens had experienced different, and unplanned, dissolution/precipitation histories, resulting in difficulties when comparing the results.

For the 2 specimens previously corroded under oxic conditions, the contact with the bicarbonate groundwater during the 7th contact period resulted in decreased release fractions for Np and Pu, the expected increased release fractions for U, and also increased release of Rb, and above all of Cs and Mo. In the case of Mo, the increase in the cumulated release fraction due to this re-dissolution step gives values of the same order as for Cs, which is not observed even for tests performed under GW-OX conditions, so the results are unexpected with respect to the amounts apparently re-dissolved. Unfortunately, perhaps due to the uncertain course of corrosion during the previous contacts, there appears to be no evidence of a constant pattern in the ratios of the release fractions or molarities of the released species.

The effects of the change from deionised water under anoxic conditions to groundwater also under anoxic conditions, (specimen 11-13), were marked only by an increased molybdenum release, and a much decreased uranium fractional release.

It must be pointed out here, however, that these observations may be caused, at least partly, by the experimental procedure for imposing anoxic conditions in the corrosion vessels during contact periods 7-9, which is suspected to have been less effective than in previous contact periods. This effect will be discussed in detail in the following section of this report, particularly in connection with the evaluation of the fractional release rate data for the three specimens which were contacted for all nine contact periods with the bicarbonate groundwater under anoxic conditions, i.e., specimens 11-6, 11-9 and 11-15.

6.4 FRACTIONAL RELEASE RATES

In this section, fractional release rates, mostly the results for centrifugates from corrosion tests performed in the simulated bicarbonate groundwater under both oxic and anoxic conditions, will be discussed. Hopefully, the more extensive range of the analytical results presented in Appendix B compared with those available previously will permit a more detailed evaluation to be performed.

6.4.1 Corrosion tests in bicarbonate groundwater under oxic conditions.

It was shown in section 6.1 of this report, that the cumulated release fractions for the ten Series 11 fuel/clad specimens, after about 5 years of exposure to simulated bicarbonate groundwater under oxic conditions, showed large variations, between both the nuclide or nuclides considered, and also between the fuel/clad specimens themselves, which had bulk burnups over the range 27.0 to 48.8 MWd/kg U. The results showed the cumulative release fractions for fission products such as cesium, rubidium, molybdenum and technetium, which are known to both migrate and form segregations in operating nuclear fuel, increased with burnup and linear heat rating up to a bulk burnup level of about 45 MWd/kg U, after which they decreased. This was somewhat unexpected since the fuel with the highest burnups in the range had experienced most structural change at and near the fuel pellet rim, combined with a very high level of alpha activity in the same region. Generally, these conditions have been regarded as potentially favourable for enhanced fuel corrosion and dissolution driven by alpha radiolysis of the water in immediate contact with the fuel surfaces.

These effects can be studied in more detail by means of comparisons of the variations of the fractional release rates during the 5 years of corrosion. It is, for example, of interest to determine whether or not these differences in corrosion behaviour between the fuel specimens were constant over the whole duration of the tests.

The fractional release rates for the fission products cesium, rubidium (both Rb-85 and Rb-87), strontium, molybdenum, technetium and barium are plotted as a function of contact time in the corrodant in Figures 6-4 to 6-10. Only values for the centrifugates are presented. Note that the fractional release rate of component x is defined here as the fraction of the total inventory of component x in the particular fuel/clad segment which was found in the centrifugate, divided by the duration of the contact period in days. For comparison with the rates for the fission products, the uranium fractional release values have been used for the calculation of release "rates" which are presented in Figure 6-11.

On the basis of the cumulative release fraction results in Figure 6-1, the ten fuel/clad specimens have been considered arbitrarily as 3 groups, with burnup ranges of 27.0 to 32.7, 34.9 to 45.8, and 46.5 to 48.8 MWd/kg U respectively. The plotted points in Figures 6-4 to 6-11 are colour-coded according to this classification in order to facilitate comparison.

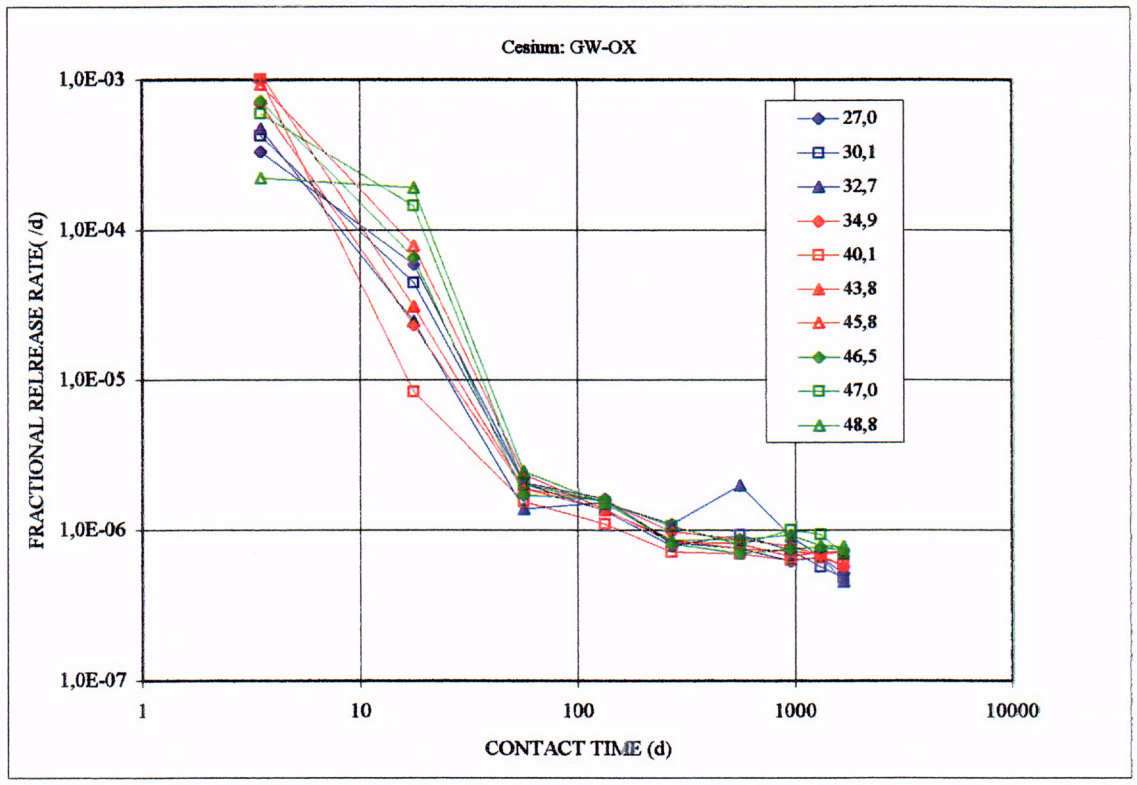


Figure 6-4. *Series 11 tests: Cesium fractional release rates (centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

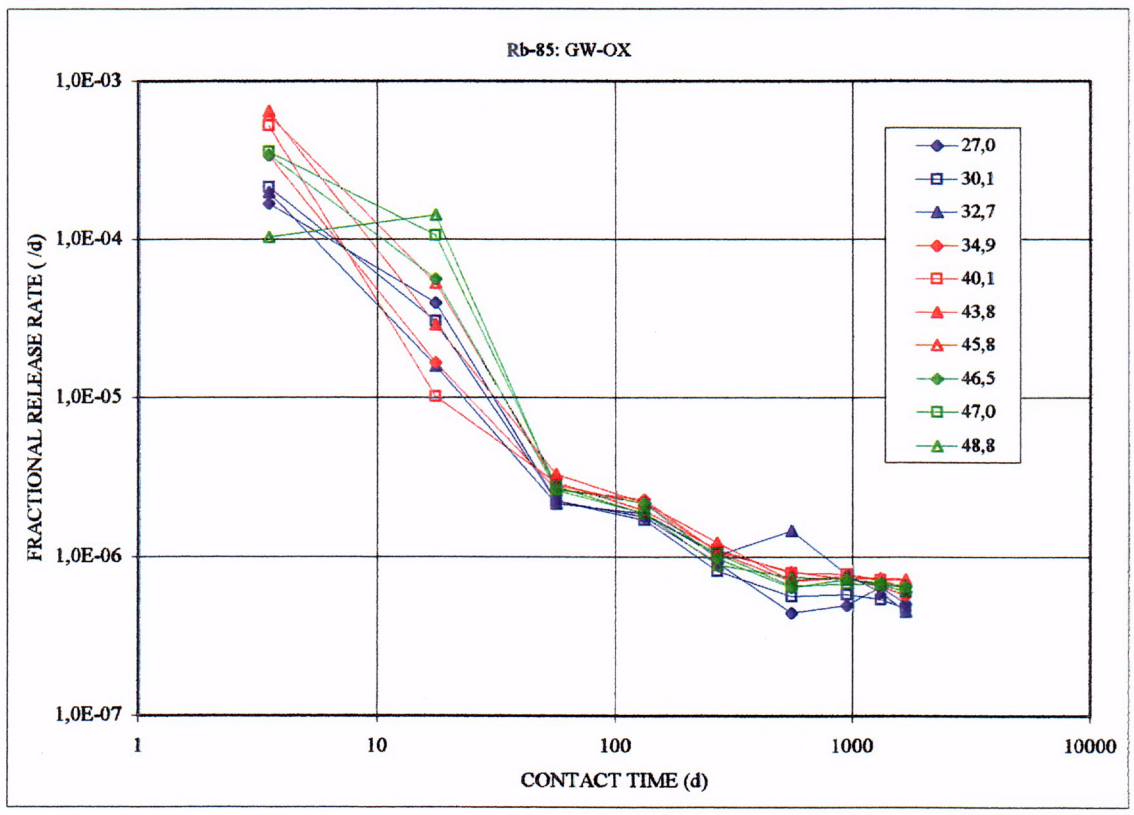


Figure 6-5. *Series 11 tests: Rb-85 fractional release rates (centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

C06

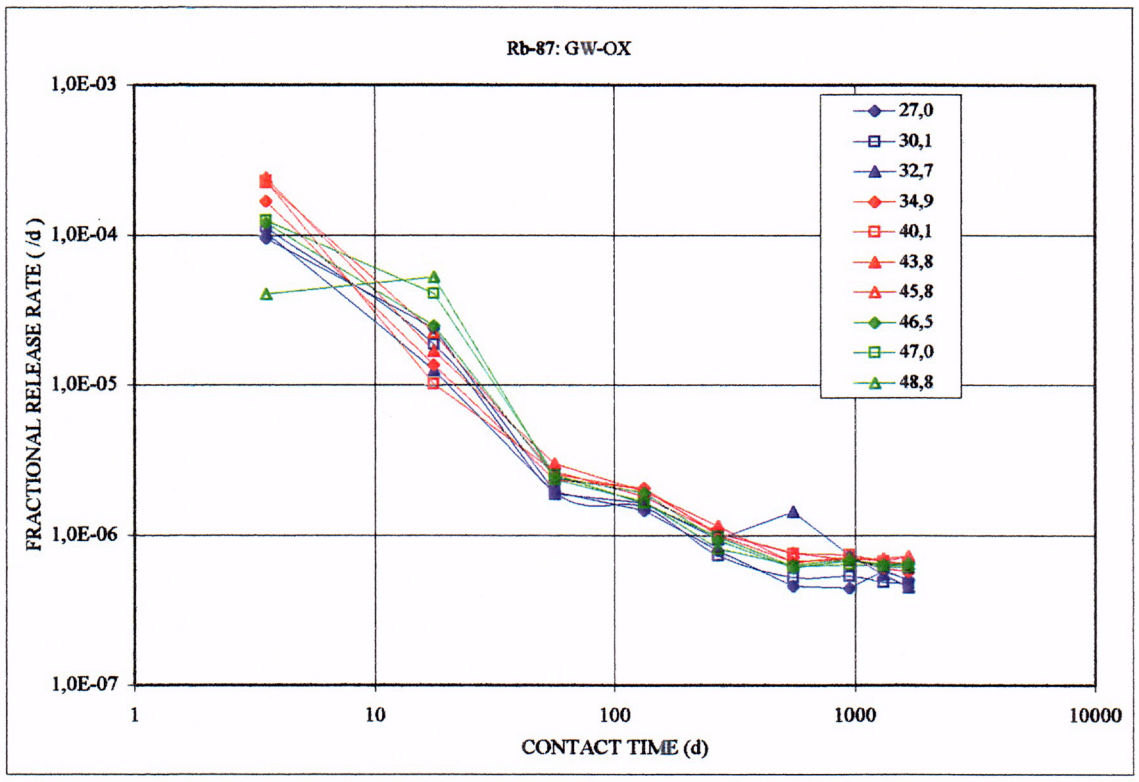


Figure 6-6. *Series 11 tests: Rb-87 fractional release rates (centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

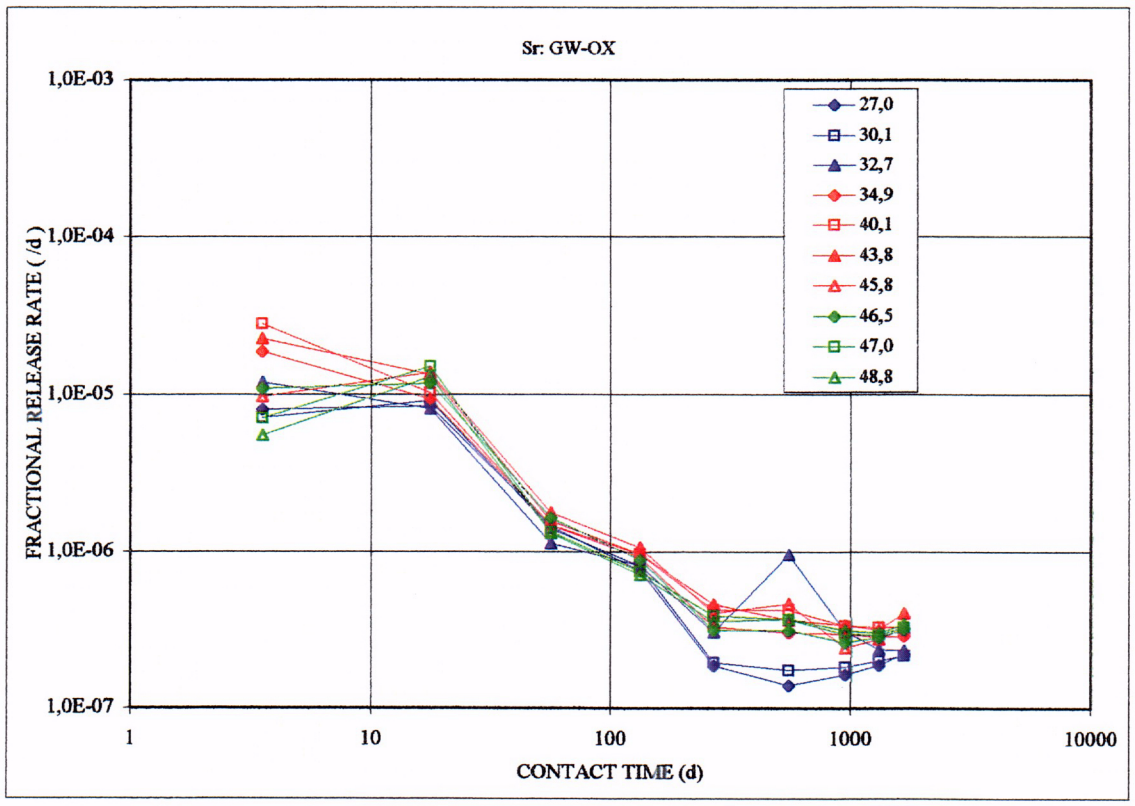


Figure 6-7. *Series 11 tests: Strontium fractional release rates (centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

C07

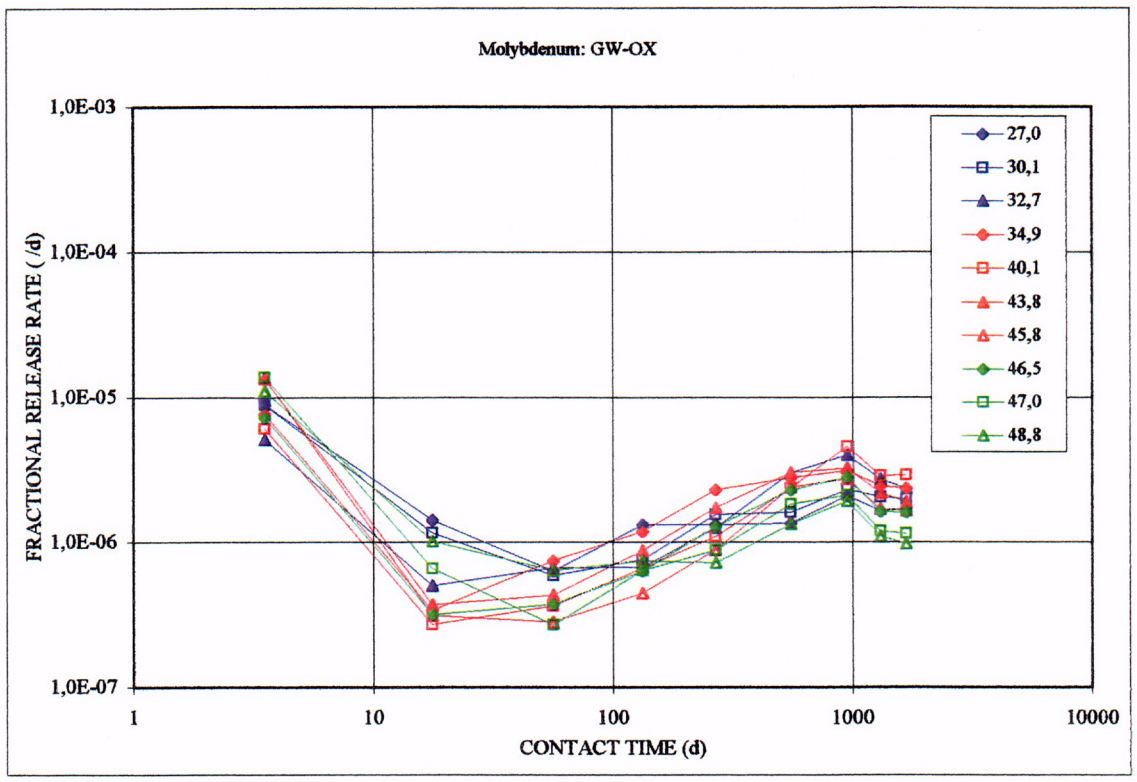


Figure 6-8. *Series 11 tests: Molybdenum fractional release rates (centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

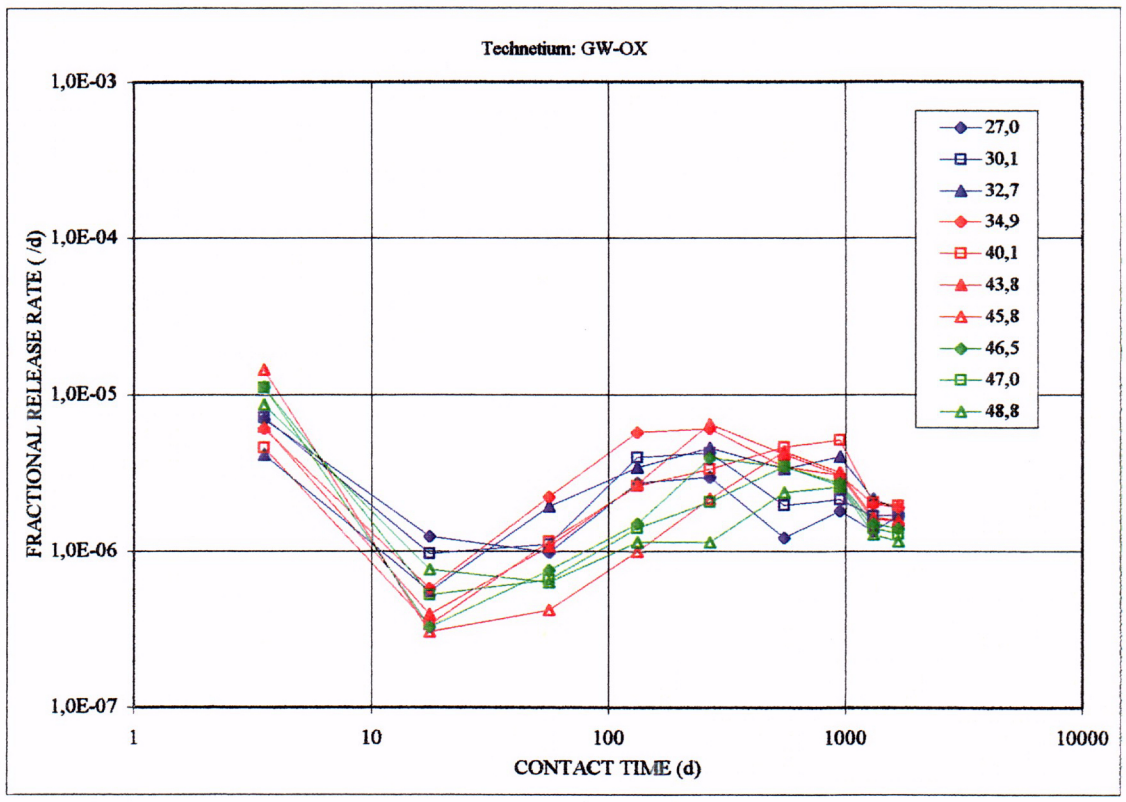


Figure 6-9. *Series 11 tests: Technetium fractional release rates (centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

C 08

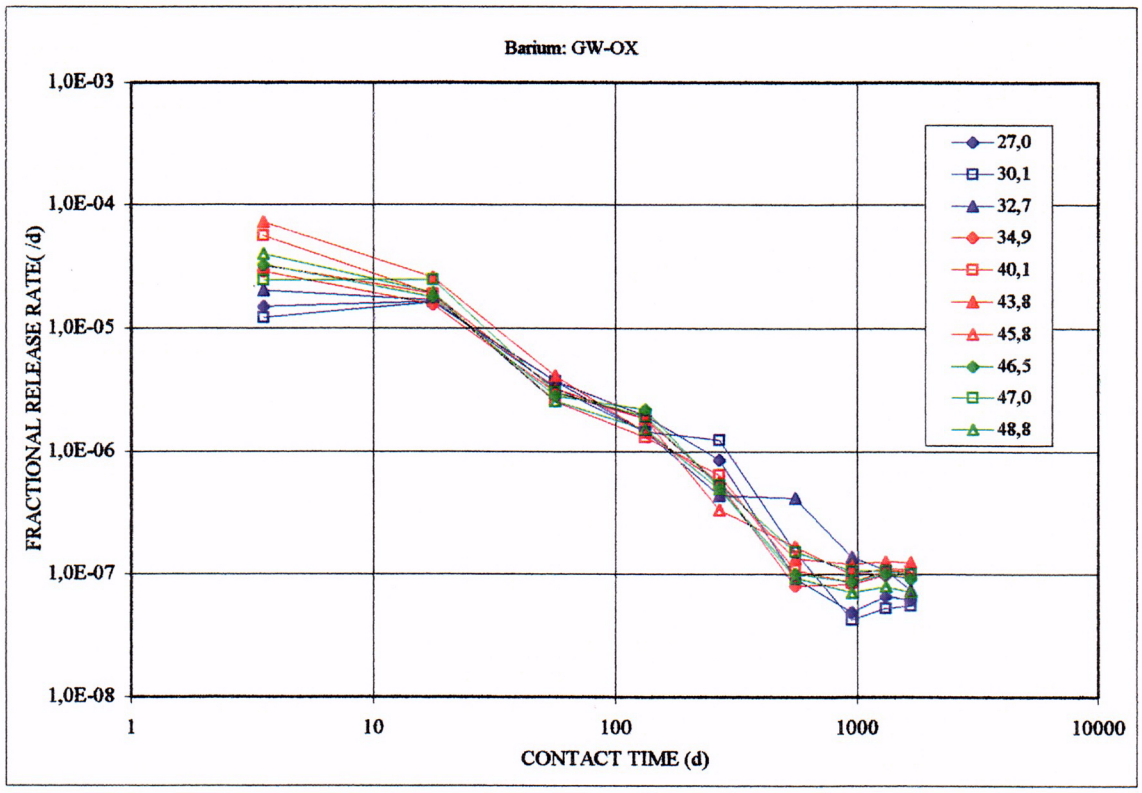


Figure 6-10. *Series 11 tests: Barium fractional release rates (centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

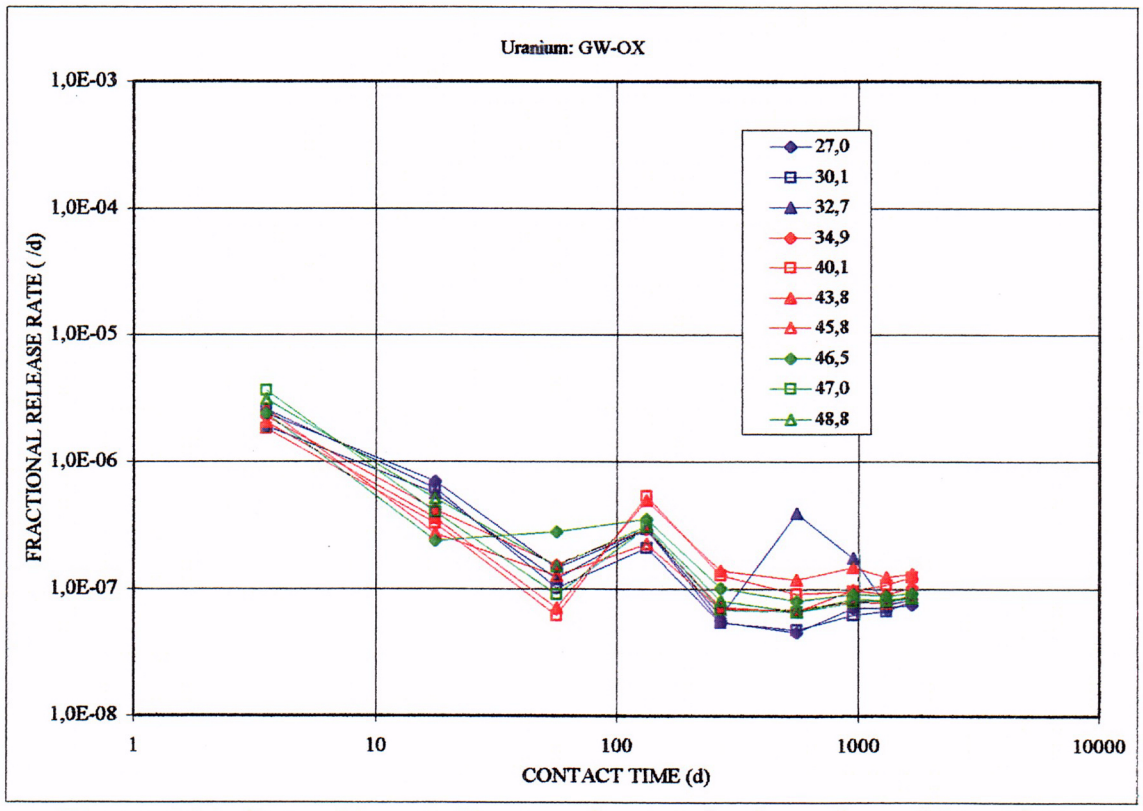


Figure 6-11. *Series 11 tests: Uranium fractional release "rates"(centrifugates) versus time and specimen burnup for the 10 tests performed under GW-OX conditions.*

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Note that the apparently anomalous behaviour of fuel specimen 11-3 during the sixth contact period, which was discussed in the preceding section, is seen clearly in Figures 6-4 to 6-11 as an abrupt increase in fractional release rate during this period. Although the high rate decreases later and approaches those of the other specimens, there is evidence in the data of an enhanced release rate even in the two subsequent periods. The release rate data for specimen 11-3, therefore, has been excluded from the average values quoted later in this section.

For the fission products cesium, rubidium, strontium and barium, with the exception of the first two contact periods and the results for specimen 11-3, there is not much scatter between the results for the nine specimens. There is larger scatter in the first two periods, which are associated with rapid solubilisation of the so-called instant release fractions (cesium and rubidium) and much higher release rates for all 4 elements than in the following contact periods. As a consequence, the fractional release values for these 2 contact periods, together 4 weeks of water contact, represent large percentages of the cumulative release fractions for the 5.09 years of corrosion: about 80% and 70% for cesium and Rb-85, about 50% for Rb-87 and barium, and about 30% for strontium.

It is also found that the differences in cumulated release fractions (5.09 years) between the specimens in the two higher burnup groups which were discussed in section 6-1, are almost entirely due to the differences in release behaviour in the first two contact periods. Further, in the higher burnup group, it can be seen that the release rates in the second 21 day contact period are very similar to those in the first 7 day period, showing that solubilisation of the fission products and their arrival in the centrifugate occur later than in the specimens in the second group. Thus, even the release rate data suggests that access of the corrodant to the fuel surface is restricted in these specimens compared to those with lower burnup.

The fractional release rate curves for molybdenum and technetium (Figures 6-8 and 6-9) are completely different from those of the other fission products discussed above. As mentioned previously in this report, this indicates a different corrosion mechanism. The metallic inclusions of Mo, Tc, Ru, Rh and Pd, which have been observed during the post-irradiation examination of spent fuel over the past 30 years, are a probable source term for the corrosion process. They have been found at about micron size in the fuel grains, at the grain boundaries, and even between the grain boundaries and at fission gas bubbles sites. By transmission electron microscopy /6-3/, particles with a size of a few tens of nanometers have been identified at or near the grain boundaries in spent PWR fuel. Thus, dissolution of the inclusions can occur by direct corrodant/inclusion contact, or during corrosive attack and fuel dissolution at grain boundaries, or even the fuel matrix itself.

Inspection of Figures 6-8 and 6-9 shows that there was an initial pulse of dissolution of both molybdenum and technetium, which may be due to a slight oxidation of the fuel, or the exposed metallic particles, during air storage before the start of the corrosion tests. After this first contact period, the fractional release rates show an apparent decrease to somewhat lower than the E-06/day level, and then show a steady increase with contact time until, after about a year of corrosion, they exceed the fractional release rates for cesium and rubidium. However, during the last two

years of corrosion, the rates for both molybdenum and technetium decrease and begin to approach the values for the other fission products.

This behaviour is consistent with a process of gradual infiltration of the micro-cracks and grain boundaries by the corrodant, oxidation of the inclusions and slow return to and mixing with the main corrodant volume. If the fuel structure in the specimens in the highest burnup group permitted a more limited ingress of water compared with the other specimens, this could explain the observation that the release rates for the specimens in this group, for both Mo and Tc, tend to be the lowest values throughout all but the first week of the corrosion test. Gradually reduced access to the fuel surface by uranium precipitation, and/or the continuous depletion in the number of inclusions readily available for water contact would account for the eventual decrease and stabilisation of the fractional release rates.

This gradual stabilisation of the fractional release rates is most marked for the fission products Cs, Rb, Sr and Ba, and the plotted values are seen to be virtually constant after 2 or 3 years of corrosion. The values presented in Table 6-11 are the average fractional release rates and their standard deviations for the specimens in the 3 burnup groups, and are the averages of the rates measured in the centrifugates in the last two contact periods, i.e., periods 8 and 9. The corresponding values for Mo and Tc are also included. Although they are not release rates, since the centrifugates were probably saturated solutions, the values calculated from the U release fractions are presented for comparison with the fission product rates.

Table 6-11. Series 11 corrosion tests: Fractional release rates after about 3 years of corrosion in bicarbonate groundwater under oxic conditions.

	AVERAGE OF VALUES FOR CONTACT PERIODS 8 AND 9.					
SPECIMEN	11-1, 11-2		11-4, 11-5, 11-8 11-10		11-11, 11-12, 11-16	
BURNUP	27.0 to 30.1		34.9 to 45.8		46.5 to 48.8	
	MEAN	S.D	MEAN	S.D	MEAN	S.D
Rb-85	5.42E-07 +/-	0.77E-07	6.85 E-07 +/-	0.59E-07	6.55E-07 +/-	0.27E-07
Rb.87	5.16E-07 +/-	0.49E-07	6.67E-07 +/-	0.55E-07	6.37E-07 +/-	0.16E-07
Cs	5.61E-07 +/-	0.78E-07	6.69E-07 +/-	0.59E-07	7.90E-07 +/-	0.81E-07
Sr	2.07E-07 +/-	0.15E-07	3.19E-07 +/-	0.40E-07	3.12E-07 +/-	0.22E-07
Ba	5.91E-08 +/-	0.62E-08	1.10E-07 +/-	0.12E-07	9.19E-08 +/-	1.40E-08
Mo	1.85E-06 +/-	0.20E-06	2.25E-06 +/-	0.48E-06	1.28E-06 +/-	0.27E-06
Tc	1.61E-06 +/-	0.17E-06	1.80E-06 +/-	0.21E-06	1.35E-06 +/-	0.12E-06
U	7.40E-08 +/-	0.61E-08	1.07E-07 +/-	0.20E-07	8.64E-08 +/-	0.46E-08

Clearly, the fractional release rates for the two specimens with the lowest burnup are also the lowest values of the nine fuel specimens at this stage in the corrosion process. For the other two burnup groups, however, although it is known from the cumulated release fractions that the highest burnup group has experienced significantly less total release to the corrodant than the intermediate group, this is not evident from these average rates late in the corrosion process, with the exception of molybdenum and technetium which are lower than for the low burnup group.

The release rate data for the rubidium isotopes and cesium presented in the table are in good agreement, and in this respect the ICP-MS data is a useful complement. It had been hoped that the data for barium would represent a similar sort of corroboration for the strontium results, but, although the cumulative release fractions for these two elements were rather similar (see Figure 6-1), the fractional release rates given in Table 6-11 differ by a factor of about 3. It can also be noted that the Ba release rates early in the corrosion process were significantly higher than those for strontium.

It has been shown above that the steady state fractional release rates are dependent to some extent on the fuel burnup in the Series 11 fuel, with the same pre-irradiation specifications, but with different linear power ratings and burnups. It is also of interest to compare the corrosion behaviour, as measured by the fractional release rates, of fuel specimens with similar nominal burnups but from **different fuel batches and of different types.**

Accordingly, the fractional release rates for selected fission products from fuel specimens in the Series 3 and 7 corrosion tests, are compared in Figures 6-12 and 6-13 with the results from specimens in the Series 11 corrosion tests with comparable burnups; viz., specimens 11-5 and 11-8, with bulk burnups of 40.1 and 43.8 MWd/kg U respectively, which bracket the Series 3 and 7 bulk burnups of 42.0 and 43.0 MWd/kg U respectively. Fractional release rates for cesium, rubidium (Rb-87) and strontium are presented in Figure 6-12, and barium, molybdenum and technetium in Figure 6-13.

Only the results from the latest contact periods for the Series 3 and 7 corrosion tests are included. This is partly because ICP-MS results were available only for these samples, partly because of the inadvertent low pH periods during the Series 3 tests, and because in the Series 7 tests, the earlier contact periods were of such long duration that the release results can not be plotted meaningfully against any specific contact time.

The agreement between the fractional release rates for the three fuel types is seen to be reasonably good. There is, of course, some scatter in the data, but this is not surprising when it is considered that results for two fuel/clad segments from the Series 3 tests, and four from the Series 7 tests are included in the comparison.

A comparison with the fractional release rates determined during corrosion tests on **fuel fragments** is of particular interest since the water to fuel ratio, and the ease of access of the corrodant to the fuel surfaces are very different compared with fuel/clad segments. Only two relevant corrosion tests under oxic conditions on fuel fragments have been performed in the programme, and as these were both performed after commissioning of the ICP-MS instrument, results are available for the more extensive analytical menu.

The tests were the final 118 day contact periods for two wedge-shaped fuel fragments, 3.23 and 3.24, which were separate experiments in the Fuel fragment/ Variable bicarbonate experiment, /2-2/. Prior to these tests, the fragments had been

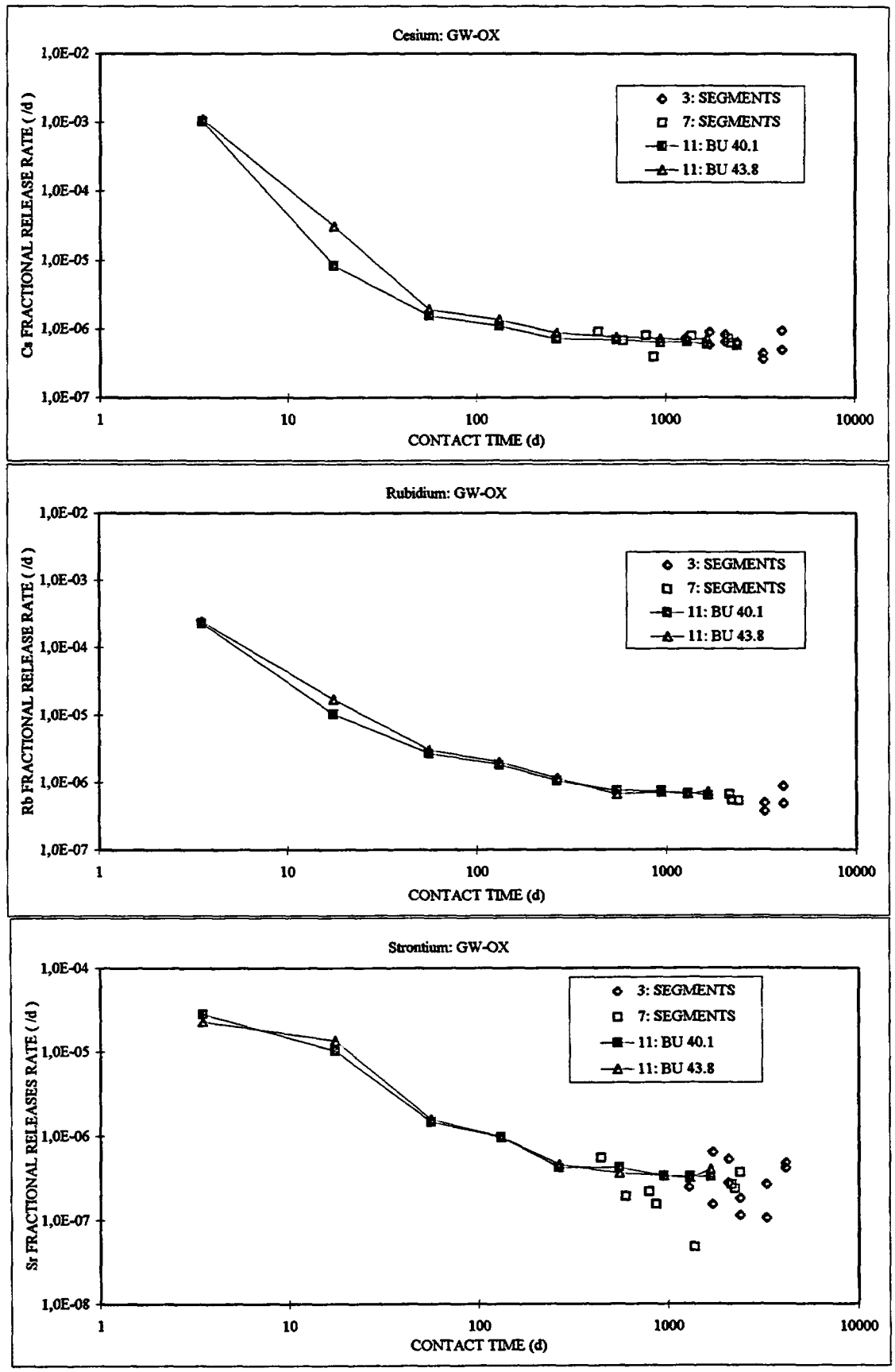

Figure 6-12. Comparison of fractional release rates for Series 3 and 7 centrifugates with Series 11 specimens with similar burnups. GW-OX conditions.
Upper) Cesium Middle) Rubidium Lower) Strontium

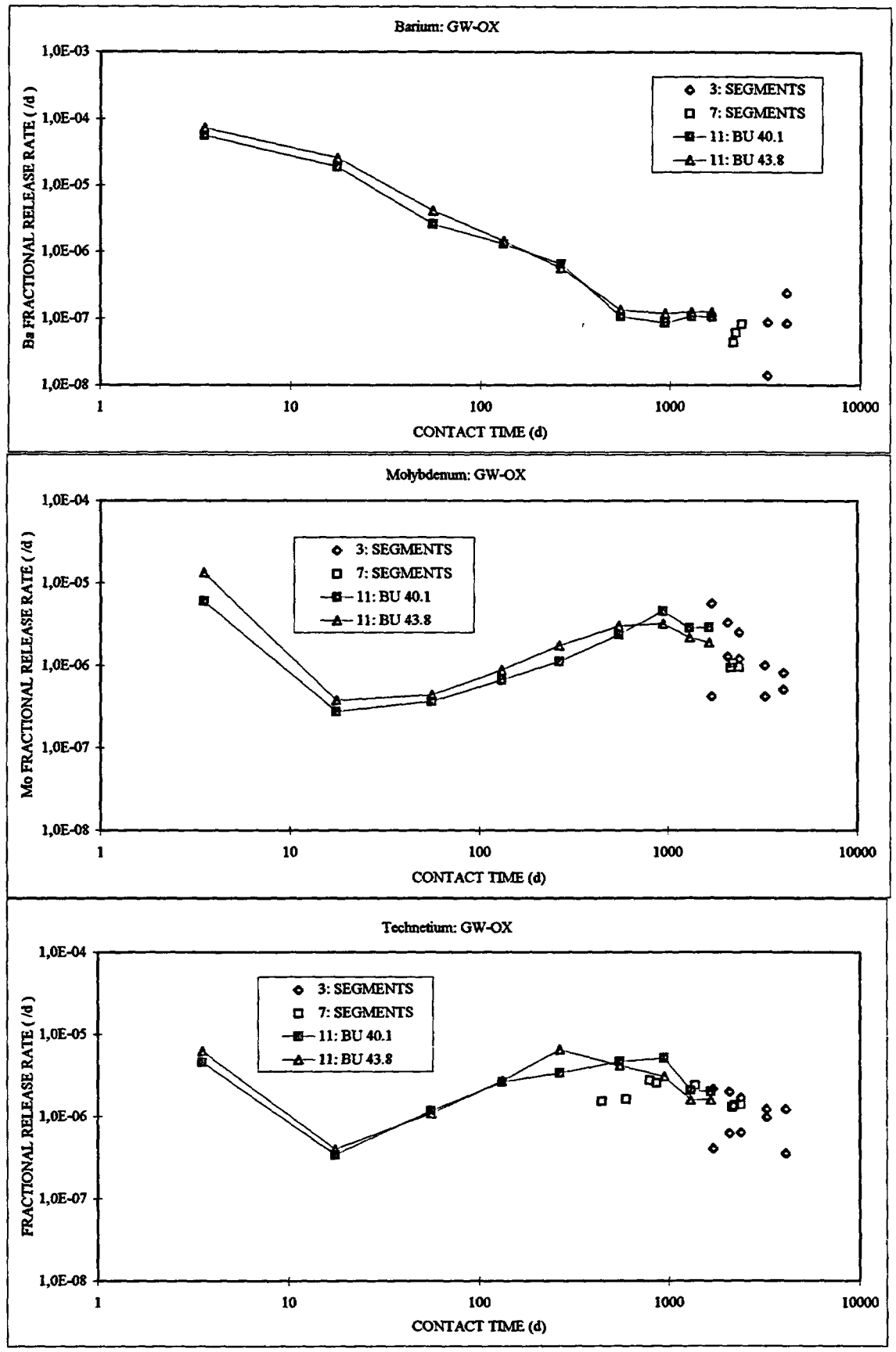

Figure 6-13. *Comparison of fractional release rates for Series 3 and 7 centrifugates with Series 11 specimens with similar burnups. GW-OX conditions.*
Upper) Barium Middle) Molybdenum Lower) Technetium

exposed to corrosion in bicarbonate groundwater with 60 and 123 ppm carbonate respectively during very long static corrosion periods (2343 days). The groundwater used in these concluding GW-OX tests was the standard simulated 123 ppm bicarbonate groundwater used in most of the corrosion programme /1-1/, and the fuel fragments, less than 1 gram in weight, were contacted with 200 cm^3 of the water. In Table 6-12, the fractional release rates determined in these two tests are compared with the values obtained for specimens 11-5 and 11-8 in the Series 11 tests.

Table 6-12. Comparison of fractional release rates (/d): fuel fragments from the Series 3 tests and fuel/clad segments from the Series 11 tests. (Groundwater under oxic conditions)

SPECIMEN	3.23	3.24	11..5	11.8
FUEL WT (g)	0.9804	0.9891	17.030	14.288
BURNUP	42.0	42.0	40.1	43.8
CONTACT (d) TIME	118	118	301* 413	300* 413
PREVIOUS (d) CONTACTS	2343	2343	1148	1148
FRACTIONAL RELEASE RATE (/d)				
Rb-85 Rb.87	3.03E-06 3.07E-06	3.05E-06 3.08E-06	6.79E-07 6.60E-07	7.18E-07 7.02E-07
Cs	2.87E-06	4.20E-06	6.22E-07	7.09E-07
Sr	2.12E-06	1.94E-06	3.30E-07	3.60E-07
Ba	2.18E-06	3.27E-06	1.07E-07	1.26E-07
Mo	3.87E-06	3.78E-06	2.88E-06	2.05E-06
Tc	2.37E-06	2.76E-06	2.02E-06	1.60E-06
U	2.54E-06	1.03E-06	1.18E-07	1.29E-07

* The tabulated release values are the averages for the two contact periods.

Inspection of the data in Table 6-12 leads to a number of observations;

a) The higher water/fuel ratio in the fuel fragment tests gives a uranium release **fraction** about an order of magnitude higher than in the fuel/clad segment tests. In the test with fragment 3.23, the higher carbonate concentration in the final contact compared with the long static contact period appears to have further increased the U concentration in the centrifugate by re-dissolution of previously deposited uranium.
b) The fractional release rates for both the fuel fragments are close to those indicating congruent dissolution.
c) For the Rb isotopes, cesium and strontium, the fractional release rates for the fuel fragment tests are 4 to 6 times higher than the corresponding rates for the fuel/clad segments. The rates for Mo and Tc are only about 1.5 times higher.
d) The high ratios between the rates for barium release may indicate that the apparent discrepancy between the Sr and Ba release rates seen earlier in this report may be due to loss of barium by precipitation on to fuel surfaces in the tests with fuel/clad specimens.

6.4.2 Corrosion tests in bicarbonate groundwater under anoxic conditions.

Only 3 specimens in the Series 11 tests, 11-6, 11-9 and 11-15, with bulk burnups of 41.4, 44.9 and 48.4 MWd/kg U respectively, were exposed to corrosion in the bicarbonate groundwater under anoxic conditions for all 9 contact periods. Figure 6-14 shows the variation with contact time of their fractional release rates for cesium, rubidium-87 and strontium; the figure also includes fractional release rates for the GW-ANOX specimens in the Series 7 corrosion tests for comparison. The corresponding comparisons of the barium, molybdenum and technetium fractional release rates are presented in Figure 6-15, and for uranium "rates" in Figure 6-16.

The measured concentrations in these specimens are lower than in the corresponding GW-OX corrosion tests, and in consequence the accuracy and precision of the analytical results can be expected to be poorer. Also, although the experimental conditions are nominally anoxic in these un-instrumented tests, the values of Eh are probably significantly different from experiment to experiment, and even during the individual tests. In spite of these problems, and those discussed below, it is felt that the agreement between the results is acceptable.

However, it can be seen in Figures 6-14 and 6-15 that the fractional release rates for the six fission products show a trend towards increasing values during the last three contact periods, and the same trend is seen particularly clearly in Figure 6-16, where there are steep rises in the results for uranium. During contact periods 1-6, the anoxic conditions in these three tests, together with test 11-13 (DW-ANOX), had been imposed on the solutions by flowing Ar/H_2 gas over the corrodant solution surface, and the four corrosion vessels were coupled together in series in the gas train.

After the conclusion of the sixth contact period of the Series 11 corrosion tests, this gas train was successively lengthened as decisions were made to extend the number of corrosion tests performed under anoxic conditions. The additional tests comprised tests on specimens 11-7 and 11-14 (changed from DW-OX to GW-ANOX), tests 7-11-4 and 7-12-4 (previously contacted with groundwater reduced by flowing through a column of crushed rock), and the 3 GW-ANOX contact periods applied to the fuel fragments in the 3-23 and 3-24 corrosion tests (See Table A-2 in Appendix A).

The reason for extending the existing gas train instead of forming new, was acute shortage of space in the hot-cell used for the corrosion tests. However, the observed increases mentioned above in the fractional release rates in the tests following introduction of the additional specimens, together with similar effects for specimens 11-7, 11-13 and 11-14 (discussed in section 6.3), strongly suggest that the efficiency of the process for imposing anoxic conditions was poor during contact periods 7-9 for the Series 11 tests.

Therefore, the fractional release rates for the 6th contact period have been selected here as most representative of anoxic conditions, and the values for the three fuel specimens, 11-6, 11-9 and 11-15 are presented in Table 6-13.

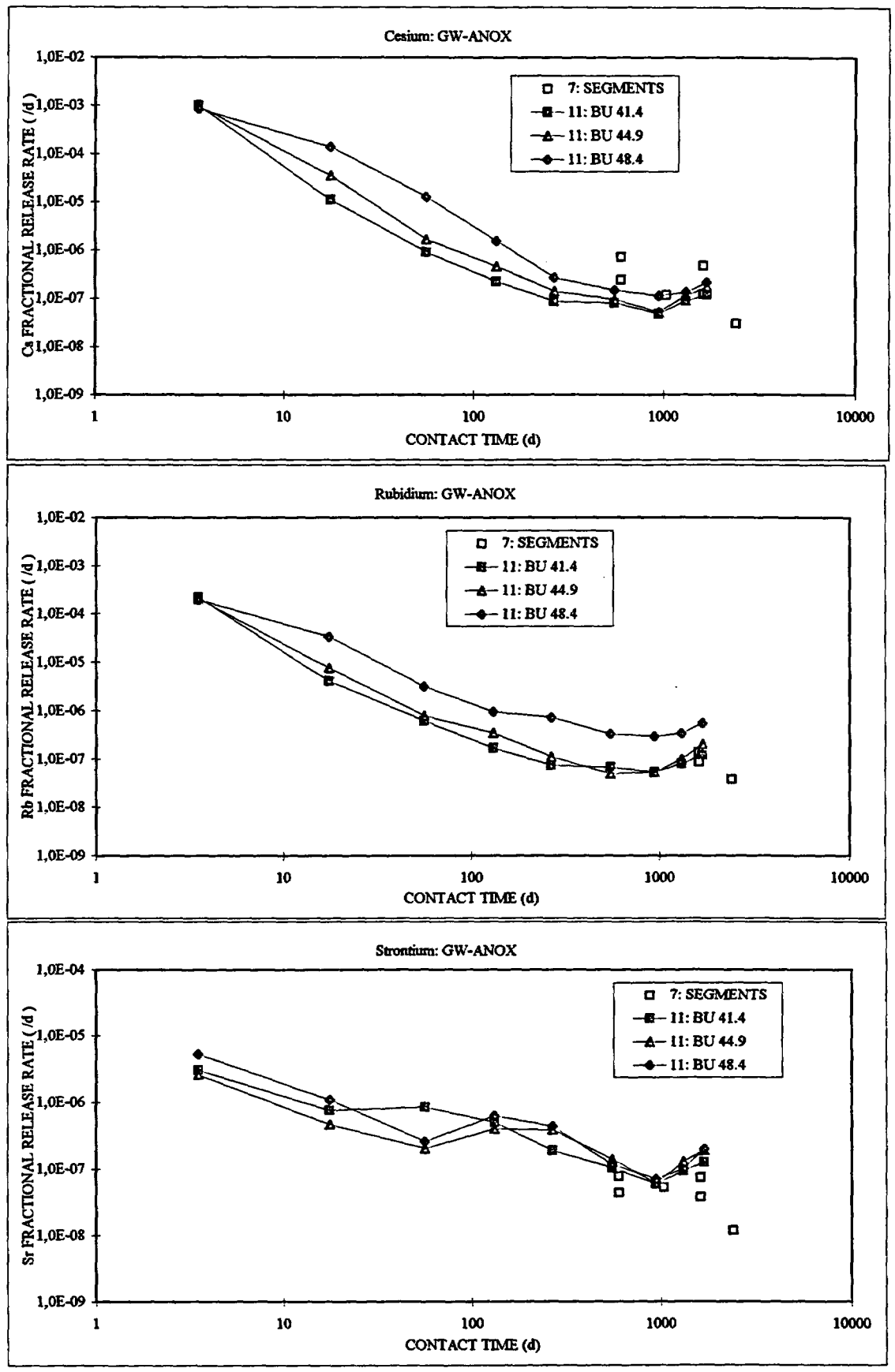

Figure 6-14. *Comparison of fractional release rates for Series 7 specimens with the three Series 11 specimens. GW-ANOX conditions.*
Upper) Cesium Middle) Rubidium Lower) Strontium

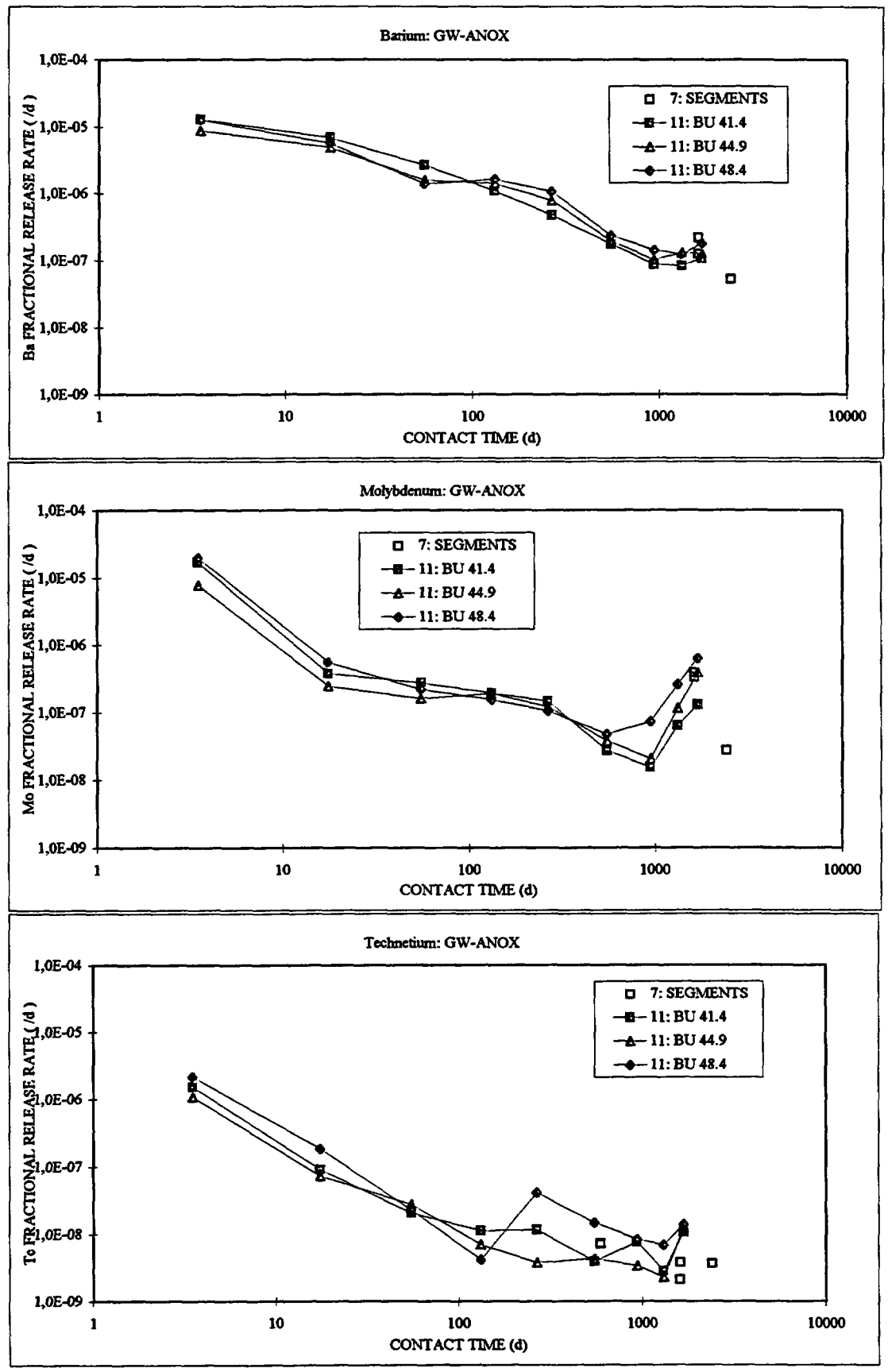

Figure 6-15. Comparison of fractional release rates for Series 7 specimens with the three Series 11 specimens. GW-ANOX conditions.
Upper) Barium Middle) Molybdenum Lower) Technetium

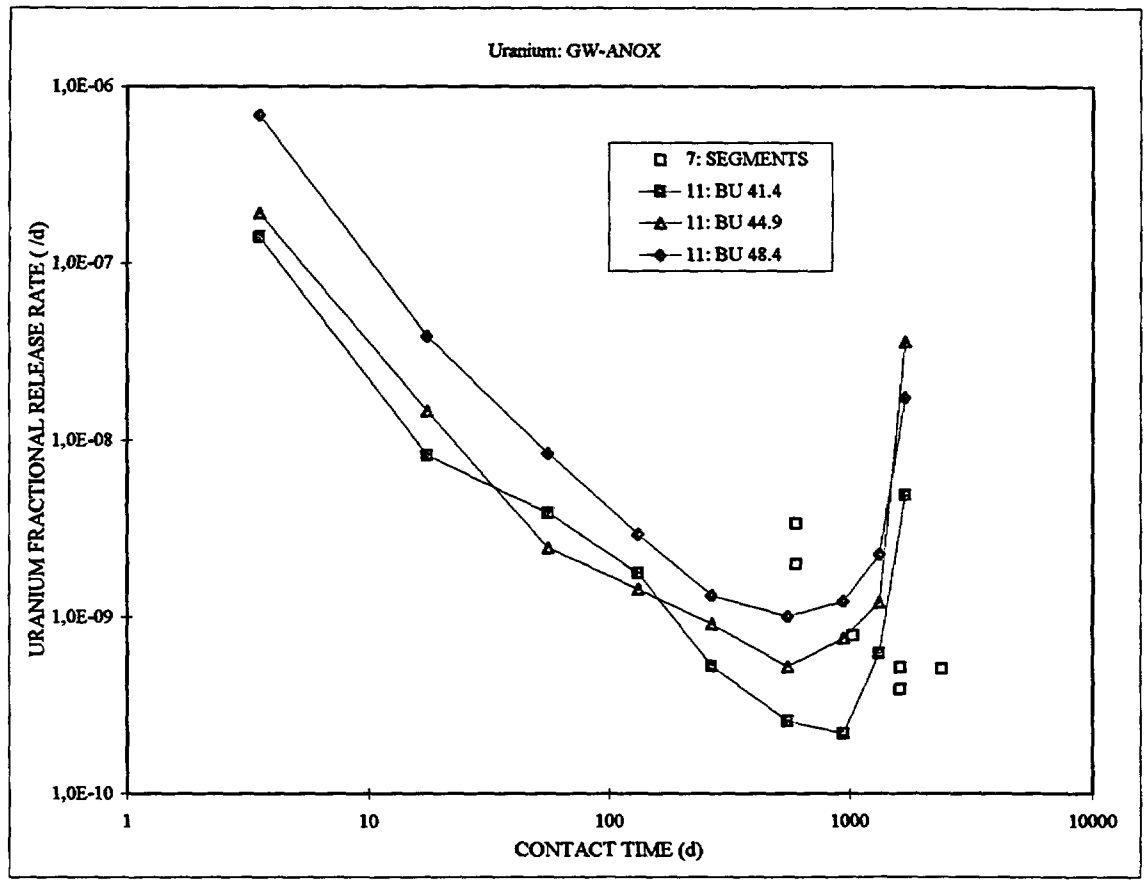

Figure 6-16. Comparison of fractional release "rates" for Uranium for Series 7 specimens with the "rates" for the 3 Series 11 specimens. GW-ANOX conditions.

Table 6-13. Series 11 corrosion tests: Fractional release rates after about 3 years of corrosion in bicarbonate groundwater under anoxic conditions.

VALUES FOR THE 6TH CONTACT PERIOD

SPECIMENS	11-6	11-9	11-15
BURNUP	41.4	44.9	48.4
Rb-85	9.30E-08	7.94E-08	1.41E-06
Rb.87	6.80E-08	4.91E-08	3.30E-07
Cs	8.23E-08	9.57E-08	1.48E-07
Sr	1.04E-07	1.39E-07	1.15E-07
Ba	1.75E-07	1.93E-07	2.35E-07
Mo	2.70E-08	3.76E-08	4.68E-08
Tc	4.02E-09	4.36E-09	1.48E-08
U	2.57E-10	5.20E-10	1.01E-09

Ignoring for the moment the fractional release rates for the rubidium isotopes, there is seen to be reasonable agreement between the results for the three specimens. There is a small apparent trend towards higher release rates as a function of specimen burnup, perhaps reflecting the alpha radiolysis effect discussed earlier,

but, when considering the comments above regarding the uncertain anoxic conditions, this trend must be considered as questionable.

The rubidium values for specimen 11-15 are very high with respect to the values for the other two specimens. In Figure 6-14, it can be seen that this has been the case for almost the whole duration of the corrosion test. The rubidium values used in the figure are those for Rb-87. In Table 6-13, the release rates for Rb-85 are much higher than the Rb-87 rates, which is unusual, since under oxic conditions, the release rates for the two rubidium isotopes usually converge after the first few months of corrosion. However, during the ICP-MS background correction procedure /1-3/, high natural background levels of natural rubidium were calculated for all the contact periods for specimen 11-15. Since there was no convincing explanation for this, an arbitrary background, based on the values for the other specimens was used. Had the calculated natural rubidium background levels been used, the values 1.00E-07 and 7.95E-08 would have been obtained for Rb-85 and Rb-87 respectively, which is in much better agreement with the values for the other two specimens.

With the exception of the results for Mo and Tc, and, of course, uranium, it can be seen that there is a greater degree of convergence between the fractional release rates for the fission products than was the case for oxic conditions. It is, therefore interesting to compare the above results for fuel/clad segments with the few results available for fuel fragments under anoxic conditions which are presented in Table 6-14.

Table 6-14. Fractional release rates in simulated bicarbonate groundwater under anoxic conditions for the fuel fragment corrosion experiments.

SPECIMEN	3.23	3.24	3.24
FUEL WT (g)	0.9804	0.9891	0.9891
BURNUP	42.0	42.0	42.0
CONTACT (d) TIME	78	78	83
PREVIOUS (d) CONTACTS	2500	2500	2580
	FRACTIONAL RELEASE RATE (/d)		
Rb-85	1.06E-06	1.92E-06	1.27E-06
Rb.87	1.07E-06	1.95E-06	1.29E-06
Cs	3.48E-06	4.33E-06	2.05E-06
Sr	2.90E-07	5.92E-07	5.45E-07
Ba	1.04E-05	4.32E-06	2.69E-06
Mo	4.73E-05	3.45E-05	1.02E-05
Tc		7.22E-08	6.89E-08
U	3.41E-08	4.76E-08	2.95E-09

The release values for the fuel fragments do not show the same degree of convergence as in the case of the fuel/clad segments, and the values for Mo are much higher which suggests that even in these tests, truly anoxic conditions were not established.

6.5 U-236/U-235 RATIOS

In section 4 of this report, the possible use of the measured U-236/U-235 ratio in uranium found in corrosion test samples as an indicator of its source (i.e., radial position) in the corroded fuel pellet was discussed. It was pointed out that the direct experimental determination of the radial variation of the ratio in spent fuel pellets has hitherto not been possible with the accuracy which would be required. An indirect method, dissolution of randomly chosen small fuel particles of the Series 3 spent fuel, and some scrapings from the pellet periphery, followed by ICP-MS analysis, has been applied /4-1/ to determine the relationship between the local U-236/U-235 ratio and the composition and quantities of the actinides at the same location. It was found that for the Series 3 fuel, there was a variation in the ratio of about 40% between the centre and periphery of the pellet.

Such measurements have not yet been performed on the Series 11 fuel, since no fuel is presently available. However, it can be expected that approximately the same radial variation would be found as for the Series 3 fuel. Here, we will assume a ratio of 1.3 between the ratio at the pellet periphery and at the pellet centre. The ratios in the fuel pellets used for the determination of fission product inventories were measured with good precision during the ICP-MS analysis campaign. The values of ratio obtained, of course, represent the ratios of the bulk fuel at these locations, since whole pellet cross-sections were dissolved and analysed.

Measurements by ICP-MS analysis of the ratios in the uranium in the Series 11 centrifugate samples from corrosion tests performed in groundwater under oxic conditions were possible with good precision, but the results on samples with low uranium concentrations, such as from tests in deionised water, or performed under nominally anoxic conditions, were usually of very poor precision due to the low counting rates in the ICP-MS instrument. The measurements of the U-236/U-235 ratios in centrifugate and vessel strip solutions from the Series 11 corrosion tests are presented in Table 6-15. Values obtained on samples with uranium contents in the range 50-150 ppb are reported in parentheses, while samples with even lower uranium concentrations and which gave results with very large scatter are indicated with an "L". The vessel strip solutions gave very few reliable results.

It is observed that the measured ratios in the samples for the first few contact periods show a scatter, usually on the low side, even in the centrifugate samples from GW-OX tests, which is rather surprising, since the uranium concentrations in these samples are about the same as in the later tests. The effect could be due to contamination with traces of natural uranium, but there is no evidence of such contamination. The ratios determined for contact periods 4-9, therefore, have been used to determine the mean values and standard deviations, which are also given in the Table. The uranium concentrations in the centrifugates from the ninth contact period for the GW-ANOX tests discussed above were sufficiently high to give reliable results, but it is seen that the DW tests always showed large scatter.

The ratios for the GW-OX and the single values from the GW-ANOX tests are plotted in Figure 6-17 together with the measured ratios of the uranium in the two inventory specimens at the ends of the fuel pellet column.

Table 6-15 The measured U-236/U-235 ratios (ICP-MS) in centrifugate and vessel strip solutions in the Series 11 corrosion tests.

CENTRIFUGATES — U236/U235 RATIOS

CONTACT	11-1	11-2	11-3	11-4	11-5	11-6	11-7	11-8	11-9	11-10	11-11	11-12	11-13	11-14	11-15	11-16
	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-ANX	DW/GW	GW-OX	GW-ANX	GW-OX	GW-OX	GW-OX	DW/GW	DW/GW	GW-ANX	GW-OX
1	0,401	0,471	0,601	0,681	1,048	[0,962]	1,212	1,228	[1,085]	1,535	1,786	1,993	2,040	1,991	1,973	2,260
2	0,410	0,482	0,669	0,828	1,216	L	1,168	1,509	L	1,707	1,559	1,856	1,843	1,930	L	2,189
3	NM	0,548	0,718	0,862	1,270	L	1,320	1,658	L	2,068	2,242	2,203	1,770	L	L	2,627
4	0,420	0,513	0,707	0,825	1,267	L	1,471	1,749	L	1,986	2,208	2,231	1,627	2,202	L	2,661
5	0,443	0,556	0,699	0,840	1,299	L	L	1,759	L	2,076	2,180	2,314	1,762	L	L	2,669
6	0,447	0,564	0,657	0,829	1,298	L	L	1,773	L	2,122	2,201	2,257	1,756	L	L	2,711
7	0,456	0,558	0,666	0,823	1,262	L	1,481	1,718	L	2,050	2,151	2,287	[1,740]	2,043	[2,091]	2,666
8	0,466	0,577	0,699	0,836	1,278	L	1,512	1,738	L	2,080	2,164	2,241	L	2,104	L	2,621
9	0,463	0,570	0,694	0,824	1,283	1,391	1,502	1,744	1,890	2,070	2,147	2,280	2,178	2,160	2,571	2,656
MEAN *	0,449	0,556	0,687	0,829	1,281	(1,391)	(1,492)	1,747	(1,890)	2,064	2,175	2,268		(2,127)	(2,571)	2,664
SD *	0,017	0,023	0,020	0,007	0,015		(0,016)	0,019		0,045	0,025	0,031		(0,060)		0,029

(* Last 6)

[ ] Indicates specimens with [U] of only 50-150 ppb

L Indicates specimens with very low U concentrations

VESSEL STRIP SOLUTIONS — U236/U235 RATIOS

CONTACT	11-1	11-2	11-3	11-4	11-5	11-6	11-7	11-8	11-9	11-10	11-11	11-12	11-13	11-14	11-15	11-16
1																
2																
3																
4																
5																
6	0,410	0,543		[0,667]	[1,037]	L	[1,366]	[1,358]	L	L	L	[1,761]	2,123	L	[1,848]	L
7	[0,410]	[0,565]	L	[0,648]	1,023	L	1,508	[1,433]	L	[1,562]	[1,583]	[1,580]	L	L	[2,017]	[2,071]
8																
9	0,421	[0,582]	L	L	[1,063]	[1,453]	1,510	L	[1,923]	[1,920]	[1,558]	[1,716]	1,969	2,102	2,280	[2,301]

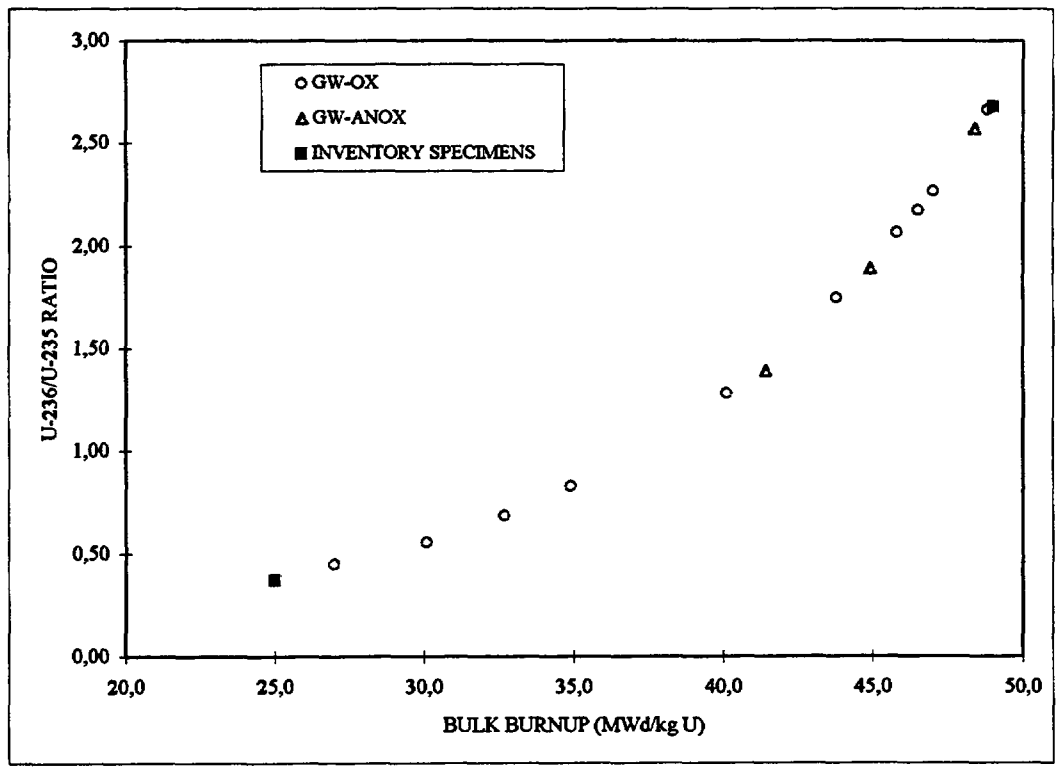

Figure 6-17. The mean U-236/U-235 ratios in centrifugates (contact periods 4-9) in the Series 11 corrosion tests compared with the ratios in the inventory specimens (bulk fuel).

Inspection of the figure shows that the centrifugate results, including the three results for nominally anoxic conditions, fit extremely well as interpolations between the values on the bulk fuel in the inventory specimens. Since the relative standard deviations of the ratio measurements on the centrifugate samples are 1-2%, and assuming a gradient in the ratio in the pellets giving a 30% higher value at the pellet periphery than at the centre, it is clear that there is no evidence of enhanced corrosion and uranium dissolution at the pellet rim, even in the specimens with the highest burnups where the potential for corrosion driven by alpha radiolysis is largest. The ratios determined on the nominally GW-ANOX centrifugates from the ninth contact times cannot be regarded as truly anoxic, so the conclusion that the dissolved uranium represents the bulk fuel, i.e., corrosion over the whole cross-section of the pellet only applies to corrosion in groundwater under oxic conditions.

7 DISCUSSION AND CONCLUSIONS

One of the main impulses for the work leading up to this report was the expanded analytical data base made possible by the commissioning of the ICP-MS instrument at Studsvik Nuclear's Hot Cell Laboratory. The decision taken at that time to apply the technique to the analysis of stored archive solutions, mainly from the Series 11 corrosion tests, and the very limited time scale available, steered the selection of direct sample analysis (i.e., without the use of chemical separation and/or concentration techniques prior to ICP-MS analysis) as the favoured method. This selection, in turn, required the rapid development of suitable software and of complicated correction procedures for isobaric interferences and natural element backgrounds. The evaluation presented above of the results in the expanded analytical data base has, hopefully, demonstrated the advantages offered by the ICP-MS technique, even though some of the aspects of the analytical campaign, which was started before full operational control of instrument operation was mastered, were less than conducive to analytical accuracy and precision.

As mentioned above, most of the expanded analytical data refers to tests performed during the Series 11 corrosion tests, which included well-characterised fuel specimens with a fairly wide range of burnups. The most recent publication of results from these corrosion tests occurred in 1992 /6-1/, when the specimens had been corroded for only one year, during five consecutive contact periods. In this report, results are available for evaluation for nine contact periods, representing a cumulative corrosion time exceeding five years. In section 6 of this report it was shown that the measured corrosion rates on these specimens had levelled out after a few years of contact, and, therefore, the present evaluation occurs at a suitable point of time.

7.1 THE EXPANDED ANALYTICAL DATA BASE

The compilation of the analytical results on which this evaluation is based has been discussed in detail in section 3.3 above, but the comments will be summarised briefly here. Prior to compilation, the data base consisted of results obtained both by the analytical methods used earlier, and by means of the direct ICP-MS analysis of sample solutions. These two different sources of results are only partly overlapping, since in general only centrifugate samples have been measured by both techniques. Further, even when results have been available from both methods, the observed loss from solution of actinides in stored archive solutions has prompted the selection of results from the earlier analytical methods which were applied on newly sampled specimens.

As mentioned in section 3.3, the specimen fission product and actinide inventories determined by the alternative methods show some differences, which are partly

unexplained. Thus, when results from both methods are available, the mean of the two values has been selected for the compilation. Since many of the results for the extra elements in the data base were determined only by the ICP-MS technique, it is obvious that the data base contains a number of analytical biases due to the selection procedures used.

With respect to accuracy of the results, it was shown in section 3.4, that on comparison of results obtained by different analytical methods for corrosion tests on fuel/clad segments, with fuel weights of about 10g for PWR specimens, and 15-18g for BWR specimens, good agreement was obtained down to release fractions of the order of E-05. At lower release fractions greater scatter between the results was observed. Since these comparisons were performed for elements such as U, Cs, Sr and Tc, which had appreciable inventories in these samples, and which were analysed by relatively straight-forward analytical procedures, it can be expected that the measurement accuracy will be poorer for other elements, particularly those with small specimen inventories. However, it is possible to compare the results for a specific element for specimens in a given corrosion test series, or even between corrosion test series.

7.2 FUEL FINES, COLLOIDS OR PRECIPITATES?

The lengthy discussion in section 5 of this report of the analytical results from the vessel strip solutions and the membrane filter specimens is only the latest in a series of such discussions starting shortly after the commencement of the SKB corrosion programme in 1982. As stated in the Introduction, the experimental procedures used in the corrosion tests in this programme were intended as a means for identification and measurement of the amounts of the (expected) actinide and, perhaps, fission product fractions of **colloids** (membrane filters) and **precipitates/adsorbates** (vessel strip solutions) formed during the tests.

Already during the evaluation /7-1/ of the results obtained during the first year (1982-83) of the experimental programme, it was concluded that the analytical results on the 65 vessel strip solutions then available showed that the activities found in these solutions were probably dissolved fuel fines, and were therefore disregarded during the evaluation. The activities found on the membrane filters, however, were assumed to represent colloidal species. The report also pointed out that the activity balances indicated that substantial amounts of the actinide elements including uranium appeared to have been deposited on the fuel/clad surfaces after the initial dissolution. As a consequence of this observation, the term Fraction of Inventory in Aqueous Phase (FIAP), which was the sum of the centrifugate and membrane filter fractions, was introduced as a better definition of the quantities actually measured.

The results which later became available from the continued corrosion tests on the reference BWR fuel /7-2/, and on the Series 7 corrosion tests using the reference PWR fuel /7-3/, gave added confirmation of the conclusion discussed above that the vessel strip solutions consisted largely of dissolved fuel fines. However, the evaluation of the larger number of results for membrane filter specimens, and, in particular, the results from experiments on samples of corrodant solutions which

were subjected to three consecutive centrifugations through three membrane filters, suggested that even the membrane filter samples contained fuel fines, and, also, that adsorption on the filter of about the same percentage of some fission products such as cesium and strontium could occur at **each** centrifugation /7-4/. However, the presence on the membrane filters of small quantities of actinides in the form of colloids could not be excluded. Further, it has also been shown that in corrosion tests with very long contact times, the vessel strip solutions can contain small amounts of fission products, in particular cesium and strontium, which are probably re-dissolved precipitates or adsorbates.

As a consequence of this more complicated situation, it became more difficult in practice to apply the same definition of the components in the FIAP term to the results for all the measured nuclides, and its use was discontinued /6-1/. The availability of the broadened data base made possible by the introduction of the ICP-MS technique has not clarified the issue, since, in particular, very few membrane filter specimens have so far been analysed by the technique.

This uncertainty regarding the interpretation of the analytical results on the vessel strip solutions and membrane filter specimens affects the evaluation of the corrosion test results in several important areas;

a) the calculation of fuel corrosion rates from the measurement of the release fractions of soluble fission products which, since they are homogeneously distributed in the fuel, serve as monitors of matrix dissolution.
b) the calculation of the amounts of uranium which can be deposited on fuel/clad surfaces in the event that the uranium concentrations in the centrifugates are solubility limited.
c) the fates of plutonium and other actinides after release to the corrodant after matrix dissolution.

With the exception of samples from corrosion tests performed in deionised water, where it is known that large amounts of fission products, particularly strontium, are retained on the membrane filters, the amounts of cesium, rubidium, strontium and possibly barium found in both the vessel strip solutions and membrane filter samples from tests performed in the bicarbonate groundwater are fairly small compared with the amounts found in the centrifugates, and, if they have not been determined experimentally, can be estimated with reasonable accuracy. As will be shown in section 7.4, the possible errors in the value of **release rates** so calculated are small compared with, for example, the effects of fuel structure on corrosion properties and the uncertainty in the estimated value of the fuel surface area subject to corrosion in the type of tests considered in this report.

As stated in section 5.1, for the nine contact periods of the Series 11 GW-OX corrosion tests, an average of about 76% of the total amount of uranium found in the vessel strip solutions was found in the strip solutions from the first two contact times. Clearly, if this material, which represents a substantial part of the calculated U "deficit" which is discussed in section 6.1, were instead regarded as precipitated uranium, the **deposition rate** curves shown in Figure 6-2 would be very different, and the concept of a rapid early decrease in fuel area exposed to corrosive attack which would explain the marked decrease in corrosion rates with time, would have

to be modified or abandoned. However, the view advanced earlier in this report that it is more probable that the observed trend of decreasing uranium contents in the vessel strip solutions as a function of the number of contact periods simply represents the successive loss of small fuel particles during sample handling is still the most favoured by the present author.

With respect to the question of the distribution of the actinides between the three sampling fractions, it can be seen in Figures 5-4 and 5-5 in this report that there is a reasonably good linear relationship between the measured release fractions of uranium in the vessel strip solutions and the corresponding release fractions of the other actinides. Figures 5-13 and 5-15 which present similar comparisons for the membrane filter specimens show much more scatter, but, significantly perhaps, the scatter is due mainly to apparently low release fractions for the other actinides, contrary to what would be expected if the presence of the actinides on the filter specimens was due to colloid formation after fuel dissolution.

It can be mentioned here that the actinide data for centrifugate samples, listed in Appendix B (release fractions) and Appendix C and Table 6-6 (molarities), appears to be of good quality, and very suitable for comparisons with code calculations as in a previous publication /6-1/.

7.3 STRONTIUM AS A MONITOR OF MATRIX DISSOLUTION?

Before the start of the SKB programme in 1982, it had been thought that Sr-90, a fission product with a high fission yield and well-established analytical procedures, would serve as a satisfactory monitor of matrix dissolution in corrosion tests on spent fuel. Although the formation of segregations of perovskite phases containing strontium in high power fuel had been reported /7-5/, it was considered that the extent of such segregation formation would be negligible in normal low power LWR fuel, and that the Sr-90 would be in solid solution in the UO_2 over the whole fuel pellet. It was surprising, therefore, that the Sr-90 release results obtained during the first year of the corrosion programme /7-1/ showed differences in release behaviour between fuel specimens which had nominally the same burnup but which had been sampled from different parts of the fuel rod. The fuel in these tests was from the Series 3 BWR reference rod, with a burnup of 42 MWd/kg U. Although the power of the fuel was rather low, with a life-averaged linear power of 18.4 kW/m, it was tentatively suggested that the apparent differences could be attributed to local differences in irradiation history due to control rod movements which were very numerous in this first reload fuel from the Oskarshamn 1 reactor.

However, control rod movements were more improbable explanations for similar effects observed some years later for Cs-137 and Sr-90 release from fuel/clad segments of the reference PWR fuel /7-3/. The cumulative release fractions for these fission products from fuel specimens from different parts of the fuel rod (odd and even specimen numbers /2-3/) are shown in Figure 7-1. It can be noted that the burnups of these four specimens, as measured by the Cs-134/Cs-137 ratios, were identical within the accuracy of measurement. (Odd-numbered specimens 0.509 +/- 0.006; even-numbered 0.510 +/- 0.007). The specimens were taken from positions

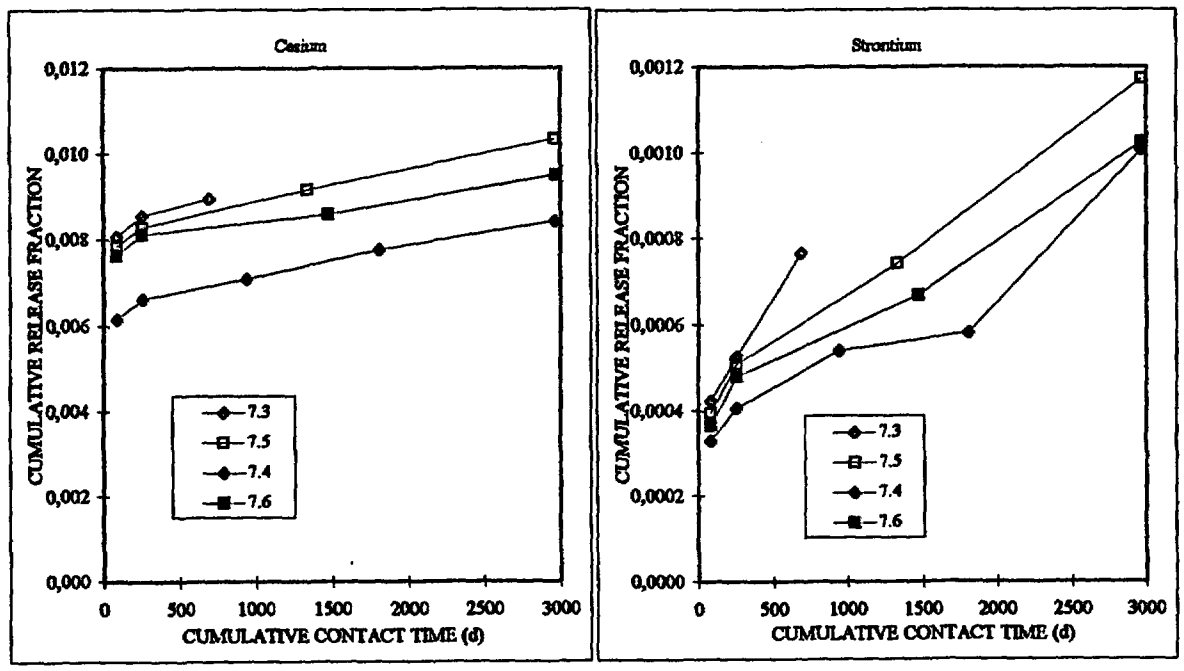

Figure 7-1. Cumulative release fractions for the Series 7 fuel/clad specimens with odd and even sample numbers. GW-OX conditions. Left) Cesium: Right) Strontium

immediately adjacent to each other between the 3rd and 4th spacer grids. The time-varying power effects would be very similar, so the observed effects are puzzling.

However, the results from the Series 11 corrosion test, which have been evaluated in this report, emphasise the relationship between fuel structural effects and corrosion behaviour. This is illustrated in Figure 7-2 which shows the cumulative release fractions for strontium and technetium for six specimens of different burnup, where

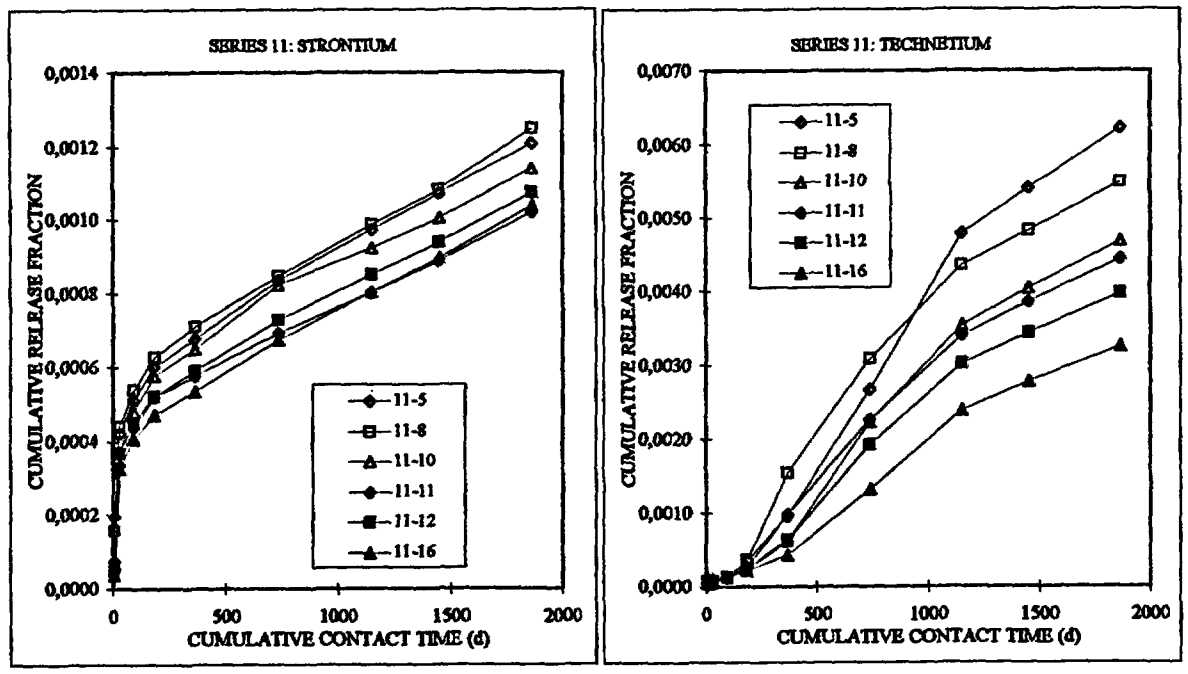

Figure 7-2. Cumulative release fractions for Series 11 fuel/clad specimens with different burnups. GW-OX conditions. Left) Strontium: Right) Technetium

the cumulative release fractions for both strontium and technetium are seen to be clearly higher for fuel specimens 11-5, 11-8 and 11-10, which had burnups of 40.1 to 45.8 MWd/kg U, than those for specimens 11-11, 11-12 and 11-16, with burnups of 46.5 to 48.8 MWd/kg U. For the lower burnup group of specimens, the higher release of strontium occurred during the first periods of water contact; in the later stages of corrosion, the release rates in the two groups of specimens were about the same. As has been shown in section 6.4, the release rate of technetium (and molybdenum) varied with contact time in a completely different way to the other fission products studied, and this is reflected in the forms of the technetium cumulative release curves shown in Figure 7-2.

Clearly, the release behaviour of strontium in these six specimens, which were from the same manufacturing batch, and had parallel irradiation histories, but differed only in having slightly different burnups and linear heat ratings, is the reverse of what would be expected if the process was dominated by the selective dissolution of small segregations at crack and grain surfaces enriched in strontium by temperature effects during irradiation. It is most probable, therefore, that the differences in strontium release behaviour observed between these specimens is due only to successive changes in **fuel structure** related to the fuel burnup and/or linear heat rating, and not to thermal migration effects.

As a corollary to the above conclusion, it is suggested here that the differences in strontium release behaviour noted and discussed above for fuel specimens in the Series 3 and 7 corrosion tests, where the specimens had very similar or identical burnup, were due more to differences in local pellet cracking pattern rather than to differences in the microstructures of the specimens at the fuel grain level.

7.4 CORROSION RATES AND FUEL STRUCTURE

Although there are large gaps in the compilations, particularly of results for membrane filters and, to a lesser extent, for vessel strip solutions, the experimental results presented here for the 16 fuel/clad segment specimens in the Series 11 corrosion tests are unusually extensive both in the number of actinide and fission product elements analysed, the time over which the corrosion process has been followed in detail (5 years), and, not least, in the number of fuel burnup levels studied. The characterisation programme of the fuel prior to corrosion testing was also very detailed with respect to radially varying properties such as fuel structure and the distribution of burnup and alpha activity.

The release behaviours of selected fission products (Cs, Rb, Sr, Ba, Mo and Tc) and uranium over the five year corrosion test, and their correlation with specimen burnup could, therefore, be followed in great detail. In section 6 of this report, it was shown that the fuel burnup had a large effect on the extent of corrosion (cumulative fractional release) over this five year period. However, contrary to what could have been expected, at burnup levels where pellet rim effects (peripheral porosity zone and high alpha activity) regarded as potentially favourable to oxidative corrosion began to develop, the total corrosion, equated here with the fission product release to the water, decreased.

Study of the variation of the fractional release rates of the fission products and uranium with water contact time showed that the burnup-related differences in release behaviour were most prominent during the first few weeks of corrosion, although there were differences in behaviour between Cs, Rb, Sr and Ba, which are probably in solid solution in the UO_2 but possibly enriched **near or at** grain boundaries, and Mo and Tc, which are also found in spherical metallic inclusions **in** the grain boundaries.

In sections 6.1 and 7.3, arguments were presented for the selection of strontium as the preferred monitor of fuel matrix dissolution, and, therefore, that its release to the corrodant can be used as a measurement of fuel corrosion. Inspection of the tables of release fractions in Appendix B, shows that, at least for the Series 11 GW-OX tests, the values for strontium in the centrifugates are always higher than the corresponding values for uranium.

After discussions in sections 5 and 7.2 regarding the origin of the uranium, actinide and fission product contents in membrane filter specimens and vessel strip solutions, it was (almost) arbitrarily decided that the uranium found in these specimens could be regarded as fuel fines, and could be ignored when examining uranium mass balances. In consequence of this decision, it was concluded that for each contact period, the difference mentioned above between the release fraction values for strontium and uranium - the uranium "deficit" - represents uranium deposited on the fuel and clad surfaces, for example in grain boundaries and microcracks, due to solubility limitations. In following discussions, it was shown that this deposited uranium would also contain large fractions of the actinides, and probably rare earth fission products, which had been brought into solution during the initial dissolution of the spent fuel. Based on these assumptions, the uranium deposition rates calculated for the Series 11 corrosion tests performed under GW-OX and GW-ANOX conditions were presented in Figures 6-2 and 6-3 respectively.

The assumption that the uranium found on membrane filters and in vessel strip solutions consisted entirely of dissolved fuel fines, of course, tends to maximise the calculated amounts of deposited uranium. To some extent this has been balanced by an under-estimation of the strontium release fractions (by about 10%) since the so-called "excess release fractions" in filters and vessel strips (see section 5) have been ignored. However, the amounts of deposit can also increase by co-precipitation or scavenging of components in the simulated bicarbonate groundwater, the composition of which is shown in Table 7.1.

Table 7-1. Composition of the simulated bicarbonate groundwater.

Species	HCO_3^-	SiO_2	SO_4^{2-}	Cl^-	Ca^{2+}	Mg^{2+}	K^+	Na^+
Molarity	2.014E-3	2.056E-4	1.000E-4	1.973E-3	4.477E-4	1.774E-4	1.000E-4	2.836E-4
ppm	123	12	9.6	70	18	4.3	3.9	65

pH: 8.0 - 8.2 Ionic strength: 0.0085

Further, since in the procedure used in these tests new groundwater is introduced after each contact period, the components corresponding to nine groundwater batches, i.e., 1.8 litres, have been available for deposition effects. These amounts

are of the same order as the calculated weights of the "uranium deficits" shown in Table 6-1. The decreased carbonate contents of the corrodants in the GW-ANOX tests shown in the tables in Appendix A, for instance, are indirect evidence of the precipitation of calcite, although there is as yet no direct experimental evidence of even the existence of the deposition layer in the corroded specimens.

In this report, it has nevertheless been suggested that such a deposited layer is formed, at approximately the rates shown in Figures 6-2 and 6-3, resulting in a rapid decrease in the contact area between fuel and water, since, after uranium saturation, deposition could be expected to occur preferentially in the fine network of connected porosity and microcracks in the fuel. The subsequent restricted water access causes the large decreases in corrosion rates, of one order of magnitude or more, observed during the first few months of corrosion, which are shown in the fractional release rate figures in section 6.

The decrease in cumulated release fractions for the fuel specimens with the highest burnups in the Series 11 tests, which has been discussed above, is also attributed to the effect of deposition layer formation, but here it is assumed that the incremental burnup increases in these specimens are associated with changes in the micro-structure of the fuel such that the surface area is reduced, or that water access is further restricted in comparison with the specimens with lower burnup. There is as yet no experimental evidence in support of this hypothesis.

The fractional release rate curves show that the strontium release rates for the ten Series 11 fuel specimens corroded under GW-OX conditions had levelled out after 1-2 years of corrosion. At that time, the release rates for cesium and rubidium had also levelled out at rates a little higher than for strontium, probably indicating some contribution from selective grain boundary attack. The fractional release rates for molybdenum and technetium, after showing very different release behaviour from that of Sr, Cs and Rb, reflecting the different nature of their source terms, (see above) had begun to approach convergence after about 5 years of corrosion.

In the corresponding GW-ANOX tests, it is not clear whether or not steady-state release rates had been attained. Air leakage during the last three contact periods was suspected so it is not known whether further decreases in rate would have occurred if anoxic conditions comparable to the first tests had been applied. After the first 6 contact periods, however, the fractional release rates for Cs, Rb, Sr and Ba were very similar, and at a level of about 30% of the value for GW-OX conditions. From the deposition rate curves (Figures 6-2 and 6-3) for this stage of corrosion for both GW-OX and ANOX conditions, it is shown that the uranium deposition rate had been reduced to only a few micrograms/day for a 20 mm long fuel/clad segment.

It was reported in section 6.5 that the ICP-MS measurements of the U-236/U-235 ratios in the uranium in centrifugate samples did not indicate that selective dissolution , for example at the fuel pellet rim, had occurred, and that the source of the centrifugate uranium appeared to be uniform corrosion over the whole fuel pellet. Unfortunately, no results for uranium in the centrifugates from true anoxic tests were available because of measurement inaccuracy at such low uranium levels.

However, this observation, which is strictly only valid for the corrosion experiments performed in groundwater under oxic conditions, is of great significance in that it suggests that fuel dissolution occurred, at least during the last six contact periods, predominantly at the open ends of the fuel clad segments.

In section 6 of this report, it was shown that the corrosion behaviour of the fuel/clad segment specimens of the two other reference fuels in the programme, the fuels for the Series 3 and 7 corrosion tests, was similar to that of fuel in the Series 11 tests with about the same burnup. The mean values of the strontium fractional release rates calculated from the results from the last contact periods for the various fuels are presented in Table 7-2. Results are given for the three burnup groups of the Series 11 tests (Table 6-11) and for both the fuel fragment and segment fuel in the Series 3 tests. The first row of values (FRR_c) are based on the release fractions in the centrifugates only, while the second row (FRR_t) have been corrected by a standard factor for strontium "excess release fractions" in the vessel strip and membrane filter specimens. (Tables 5-1 and 5-2)

Table 7-2. Fractional release rates (strontium) for the reference fuels in the SKB programme after 5 years or longer of corrosion: GW-OX conditions.

FRACTIONAL RELEASE RATES (/d)

Fuel	Series 3 BWR		Series 7 PWR	Series 11 BWR		
Type	Fragment	Segment	Segment	Segment	Segment	Segment
Burnup	42.0	42.0	43.0	27.0 - 30.1	34.9 - 45.8	46.5 - 48.8
FRR_c	2.03 E-06	3.20 E-07	2.91 E-07	2.07 E-07	3.19 E-07	3.12 E-07
FRR_t	2.27 E-06	3.58 E-07	3.25 E-07	2.31 E-07	3.56 E-07	3.49 E-07

There is seen to be very good agreement between the results for the fuel/clad segment tests. The mean value of the fractional release rate for the fuel fragment tests, where individual fuel fragments of only about 1 gram in weight were exposed to 200 cm^3 of water, is about six times higher than the value for the segments.

Although there are significant differences in experimental procedure with respect to both the fuel specimens and their exposure to the corrodants, the corrodants used and the handling of the corrodant solutions prior to analysis (the use of filters, for instance), comparison of the SKB results on fuel/clad segments with the results in two excellent reports from other programmes which have been published recently /7-6, 7-7/ also shows surprisingly good agreement. Among other results, the latter report presents and discusses fuel dissolution rate data obtained by means of flow-through tests on fuel specimens with different burnup, morphology and pre-treatment before the tests. The authors also discuss and compare the relevance for the normalisation of the experimentally determined fractional release rates, of surface area measurements on spent fuel specimens by both the BET method and a method based on particle size distribution.

In the Studsvik Hot Cell Laboratory some BET measurements of the surface area have been performed on the Series 3 and 7 reference fuels /4-1/ giving results in

the range 60-120 cm^2 / gram depending on the fragment size fraction examined. These values, determined using krypton as the adsorbed gas, are generally regarded as too high for use in calculating area-normalised dissolution rates for fuel/clad segment specimens, since the access of water to the inter-connecting surface network in spent fuel will probably be more limited than that of krypton.

In the Battelle work /7-7/, however, the use of calculated specimen surface areas, which were based on the particle size distribution and the assumption of idealised cubic morphology, (PSD method) was found useful for normalisation and comparison of the measured fractional release rates. Since a factor of almost exactly 3 was found between the BET and PSD results for the surface area of unirradiated UO_2 powder, a roughness factor of 3 was used for correction of the areas calculated for idealised cubes.

In the following, this methodology will be applied to the fractional release rates presented above in Table 7-2. The dissolution rates will be expressed as milligram of fuel dissolved per m^2 and day, and the fuel weights are the average of those of the individual specimens, or for an idealised segment length.

The surface areas have been calculated by several methods. For the Series 3 fragment tests, the mean of the weights of the 2 fuel fragments has been used to calculate the size of an equivalent cube, and to its calculated surface area, a roughness factor of 3 has been applied. Two methods have been used for the fuel/clad segments:

a) By means of the fuel fragment size distribution results published earlier for the Series 3 and 7 reference fuels /4-1/, the total surface area of the fuel fragments in the segment were calculated, and corrected with the roughness factor of 3.
b) Reflecting the discussion above on the formation of deposition layers during corrosion, as a simplification, it is assumed that after five years, all dissolution occurs at the two open ends of the segment. However, the calculated planar areas at the ends are first increased by an arbitrary 50% to take account of the unevenness of the fragment surfaces (see Figure 4-3), before applying the roughness factor.

The results so corrected are shown in Figure 7-3.

Table 7-3. Normalised dissolution rates for the fuels in the SKB programme.

Fuel	Series 3 BWR		Series 7 PWR	Series 11 BWR
Type	Fragment	Segment	Segment	Segment
Burnup	42.0	42.0	43.0	34.9 - 45.8
FRR_t	2.27 E-06	3.58 E-07	3.25 E-07	3.56 E-07
Wt. Fuel (g)	0.9848	17.37	11.91	17.37
S.A. (fragments) (m^2)	3.74 E-04	8.61 E-03	6.72 E-03	8.61 E-03
S.A (segment ends) (m^2)		7.79 E-04	5.73 E-04	7.79 E-04
NORMALISED DISSOLUTION RATE ($mg.m^{-2}.d^{-1}$)				
Fragments	5.97	0.72	0.58	0.72
Segment ends		7.97	6.75	7.93

Note that for the fuel/clad segment specimens, there is a factor of about ten between the surface areas calculated by the two methods, which could correspond with the experimentally observed decrease in fractional release rates during the first months of corrosion. However, it is felt that the effective surface areas calculated by the "segment ends" method for these specimens are somewhat under-estimated.

The dissolution rates given in Table 7-3 show that there is reasonable coherence between the tests on different fuels, and between fuel fragments and segments within the SKB programme. They also appear to bracket most of the relevant results reported from the Battelle programme. /7-7/

Much of the evaluation approach in this report has been based on hitherto unverified assumptions or approximations. Clearly, more work needs to be done on the detailed examination of post-corrosion fuel specimens, and on specially designed experiments to test and/or confirm some of the hypotheses advanced.

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REDOX CONDITIONS — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3-1	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	GW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX
3-2	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX
3-3	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	

CONTACT TIME (days) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3-1	7	7	14	63	91	182 *	182	159	218	174	367	479	238	399	1366	337	
3-2	7	7	14	63	91	182 *	182	159	218	174	367	479	238	399	1366	337	
3-3	7	7	14	63	91	182	182	159	218	174	367	479	238	399	1366	337	

* The 6th period was divided into 2 periods.

pH (CENTRIFUGATE) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3-1	NM	NM	7,30	7,00	3,90	7,50/7,00	5,70	6,50	3,85	5,20	8,15	8,25	6,80	7,00	7,90	6,8/7,5	
3-2	NM	NM	8,10	8,20	2,30	8,20/8,25	8,05	8,00	4,25	6,60	8,15	8,20	8,20	8,30	8,43	8,30	
3-3	NM	NM	8,10	8,20	4,75	8,20	8,05	8,00	4,20	5,10	8,15	8,35	8,40	8,30	8,50	8,50	

[CARBONATE] (ppm) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
3-1	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	9	3	<6	<6	
3-2	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	125	146	110	103	
3-3	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	NM	154	151	123	120	

Table A-1. Series 3 Corrosion test programme. Fuel/clad segments from Oskarshamn-1 BWR reference fuel rod.

REDOX CONDITIONS — CONTACT PERIOD

SPECIMEN	1	2	3	4	5
3-23	GW-OX	GW-OX	GW-OX	GW-ANOX	
3-24	GW-OX	GW-OX	GW-OX	GW-ANOX	GW-ANOX
3-25	GW-OX	GW-OX			
3-26	DW-OX	DW-OX			

CONTACT TIME (days) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5
3-23	501	1842	118	78	
3-24	501	1842	118	78	83
3-25	501	926			
3-26	501	1020			

pH (CENTRIFUGATE) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5
3-23	NM	8,20	8,48	9,75	
3-24	NM	8,70	8,50	9,90	9,90
3-25	NM	8,80			
3-26	NM	6,30			

[CARBONATE] (ppm) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5
3-23	70	60	118	58	
3-24	179	119	130	78	65
3-25	257	279			
3-26	9	< 10			

NOTES

GW	GROUNDWATER
DW	DEIONIZED WATER
OX	OXIC CONDITIONS
ANOX	ANOXIC BY MEANS OF FLOWING H2/Ar
REDH2	ANOXIC BY MEANS OF H2/Ar IN PRESENCE OF Pd CATALYST
REDRK	ANOXIC USING GROUNDWATER AFTER PROLONGED CONTACT WITH CRUSHED ROCK

Table A-2. Series 3.2326 Corrosion test programme. Fuel fragments from Oskarshamn-1 BWR reference fuel rod.

REDOX CONDITIONS — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6
7.1	GW-OX	GW-OX	DW-OX			
7.2	GW-OX	GW-OX	DW-OX	DW-OX	DW-OX	
7.3	GW-OX	GW-OX	GW-OX			
7.4	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX
7.5	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	
7.6	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	
7.7	GW-REDRK	GW-REDRK	GW-REDRK			
7.8	GW-REDRK	GW-REDRK	GW-REDRK			
7.9	GW-REDRK	GW-REDRK	GW-REDRK			
7.10	GW-REDRK	GW-REDRK	GW-REDRK			
7.11	GW-REDRK	GW-REDRK	GW-REDRK	GW-ANOX		
7.12	GW-REDRK	GW-REDRK	GW-REDRK	GW-ANOX		
7.13	GW-REDH2	GW-REDH2	GW-REDH2	GW-REDH2	GW-REDH2	GW-REDH2
7.14	GW-REDH2	GW-REDH2	GW-REDH2	GW-REDH2	GW-REDH2	

CONTACT TIME (days) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6
7.1	82	170	436			
7.2	82	170	1079	1629	94-04-27	
7.3	82	170	436			
7.4	82	170	686	866	1156	94-04-27
7.5	82	170	1079	1629	94-04-27	
7.6	82	170	1217	1492	94-04-27	
7.7	82	170	436			
7.8	82	170	686			
7.9	82	170	686			
7.10	82	170	1555			
7.11	82	170	2722	94-05-10		
7.12	82	170	2722	94-05-10		
7.13	82	170	686	686	1174	94-05-18
7.14	82	170	1173	1556	94-05-18	

pH (CENTRIFUGATE) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6
7.1	8,50	8,50	6,90			
7.2	8,50	8,50	6,45	7,95/7,70		
7.3	8,50	8,50	8,50			
7.4	8,45	8,50	8,30	8,42	8,61	
7.5	8,50	8,50	8,60	8,59		
7.6	8,55	8,50	8,49	8,60		
7.7	8,20	8,35	8,50			
7.8	8,00	8,25	7,80			
7.9	8,15	8,20	8,20			
7.10	8,10	7,60	7,93			
7.11	7,95	7,30	7,87			
7.12	8,10	7,70	7,76			
7.13	9,10	7,60	7,90	7,87	8,46	
7.14	8,80	7,30	8,13	8,32		

[CARBONATE] (ppm) — CONTACT PERIOD

SPECIMEN	1	2	3	4	5	6
7.1	NM	NM	20			
7.2	NM	NM	< 14	< 6		
7.3	NM	NM	163			
7.4	NM	NM	129	140	125	
7.5	NM	NM	156	131		
7.6	NM	NM	143	125		
7.7	NM	NM	NM			
7.8	NM	NM	122			
7.9	NM	NM	116			
7.10	NM	NM	146			
7.11	NM	NM	115			
7.12	NM	NM	132			
7.13	NM	NM	116	138	118	
7.14	NM	NM	170	117		

Table A-3. Series 7 Corrosion test programme. Fuel/clad segments from Ringhals-2 PWR reference fuel rod.

	REDOX CONDITIONS										CONTACT TIME (days)								
	BURNUP	CONTACT PERIOD									CONTACT PERIOD								
SPECIMEN	MWd/kgU	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	8	9
11-01	27,0	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	21	63	91	182	371	413	301	413
11-02	30,1	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	21	63	91	182	371	413	301	413
11-03	32,7	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	21	63	91	182	371	413	301	413
11-04	34,9	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	21	63	91	182	371	413	301	413
11-05	40,1	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	22	62	91	182	371	413	301	413
11-06	41,4	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	7	21	63	91	181	370	414	328	420
11-07	42,7	DW-OX	DW-OX	GW-OX	DW-OX	DW-OX	DW-OX	GW-ANOX	GW-ANOX	GW-ANOX	7	22	62	91	182	372	414	328	420
11-08	43,8	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	21	63	91	182	371	413	300	413
11-09	44,9	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	7	21	63	91	181	370	414	328	421
11-10	45,8	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	22	62	91	182	371	413	300	413
11-11	46,5	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	22	62	92	181	371	413	300	413
11-12	47,0	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	21	63	92	181	371	413	300	413
11-13	47,6	DW-ANOX	DW-ANOX	DW-ANOX	DW-ANOX	DW-ANOX	DW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	7	21	63	91	181	370	414	328	420
11-14	48,1	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	DW-OX	GW-ANOX	GW-ANOX	GW-ANOX	7	22	62	92	181	372	414	328	420
11-15	48,4	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	GW-ANOX	7	21	63	91	181	370	414	328	422
11-16	48,8	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	GW-OX	7	22	62	92	181	371	413	300	413

	pH (CENTRIFUGATE)								
	CONTACT PERIOD								
SPECIMEN	1	2	3	4	5	6	7	8	9
11-01	8,45	8,43	8,36	7,81	8,43	8,28	8,55	8,43	8,56
11-02	8,37	8,33	8,42	8,38	8,49	8,21	8,56	8,44	8,53
11-03	8,32	8,32	8,40	8,35	8,49	8,29	8,58	8,41	8,52
11-04	8,30	8,45	8,45	8,35	8,45	8,34	8,57	8,51	8,53
11-05	8,45	8,45	8,45	8,40	8,40	8,33	8,60	8,49	8,55
11-06	9,80	9,80	9,83	9,85	9,84	9,40	9,92	9,65	9,47
11-07	6,84	6,68	8,40	3,80	6,67	7,58	9,76	9,51	9,41
11-08	8,39	8,29	8,36	8,52	8,45	8,33	8,59	8,38	8,39
11-09	9,72	9,80	9,82	9,87	9,78	9,33	9,62	9,27	9,13
11-10	8,36	8,40	8,36	8,45	8,45	8,31	8,65	8,47	8,44
11-11	8,41	8,32	8,42	8,48	8,48	8,34	8,62	8,51	8,43
11-12	8,35	8,45	8,43	8,36	8,46	8,41	8,61	8,49	8,47
11-13	5,90	6,79	5,92	4,67	4,04	3,94	9,71	9,01	9,22
11-14	6,72	6,70	6,33	3,64	6,10	5,90	9,66	9,04	9,21
11-15	9,56	9,64	9,63	9,15	9,60	9,29	9,57	8,72	9,10
11-16	8,38	8,31	8,42	8,47	8,46	8,35	8,60	8,52	8,49

	[CARBONATE] (ppm)								
	CONTACT PERIOD								
1	2	3	4	5	6	7	8	9
115	115	106	139	149	148	150	122	123
128	120	112	143	136	118	145	122	126
136	128	108	136	125	121	145	123	118
150	115	112	136	143	120	149	123	127
125	138	115	134	140	120	145	131	121
65	64	56	55	58	44	57	56	69
< 14	< 14	101	< 14	< 14	< 10	56	56	73
125	121	102	120	137	120	134	121	125
61	63	45	57	58	48	62	56	63
157	132	104	131	138	120	137	125	124
164	130	109	150	136	120	137	120	127
164	123	115	143	137	120	138	121	126
< 14	< 14	< 14	< 14	< 14	< 10	67	59	54
< 14	< 14	< 14	< 14	< 14	< 10	74	61	62
67	65	50	56	64	51	68	61	81
157	128	98	125	138	118	134	119	129

Table A-4. Series 11 Corrosion test programme. Fuel/clad segments from Ringhals-1 BWR stringer rod.

Table B 1. Selected release fractions: Series 3 Corrosion tests

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.1.1			8,43E-03	4,97E-05				6,34E-06		1,35E-06	3,25E-08					
3.1.2			5,51E-04	2,08E-05				5,50E-06		2,43E-06	5,42E-08					
3.1.3			5,51E-04	1,77E-05				7,63E-07		1,57E-06	6,69E-09					
3.1.4			6,54E-04	1,09E-04				5,34E-07		3,74E-06	4,05E-08					
3.1.5			5,68E-04	3,73E-04				3,13E-04		1,35E-05	1,63E-05					
3.1.6			6,20E-05	3,11E-05				<3,8E-07		1,20E-05	6,67E-08					
3.1.6B			1,03E-04	1,09E-05				< 2,3E-07		4,86E-06	3,00E-08					
3.1.7			5,51E-05	1,81E-06				<7,6E-07		2,24E-06	3,88E-08					
3.1.8			4,65E-05	3,04E-06				<3,8E-07		2,62E-06	4,59E-08					
3.1.9			6,71E-04	3,73E-04				4,05E-04		4,86E-05	2,04E-04					
3.1.10			6,34E-04	5,59E-04				3,59E-04			1,96E-04					
3.1.11			4,99E-04	4,04E-04				4,66E-05		1,20E-07	1,88E-08					
3.1.12			2,75E-04	3,42E-05		5,66E-05	1,24E-03	<7,6E-09		5,61E-06	1,33E-08					
3.1.13			1,06E-04	8,57E-05		3,77E-05	5,14E-04	<1,5E-06		1,06E-05	4,15E-07					
3.1.14			1,13E-04	3,91E-05			7,60E-04	<3,1E-07		2,99E-06	5,21E-08					
3.1.15	2,26E-04	2,29E-04	1,76E-04	5,45E-05	8,03E-06	4,15E-05	2,79E-03	2,18E-11	2,70E-05	1,48E-06	2,27E-07	1,09E-06		1,25E-07	2,17E-07	7,00E-08
3.1.16	1,02E-04	1,03E-04	7,49E-05	7,93E-06	3,24E-06	5,68E-05	6,21E-04	1,03E-08	6,38E-05	1,67E-06	5,27E-07	1,13E-06		5,30E-07	4,45E-07	3,00E-07

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.2.1			7,10E-03	1,25E-04				6,99E-06		3,59E-07						
3.2.2			4,10E-04	6,25E-05				6,99E-07		5,82E-08						
3.2.3			3,31E-04	1,48E-04				5,52E-06		2,05E-06	1,72E-07					
3.2.4			6,15E-04	1,59E-04				6,99E-06		9,92E-07	4,20E-07					
3.2.5			1,42E-03	1,25E-03				1,03E-03		1,16E-04	6,11E-04					
3.2.6			1,18E-04	4,83E-05				1,05E-05		2,22E-07	4,59E-08					
3.2.6B			1,18E-04	2,05E-05				5,17E-06		3,25E-07						
3.2.7			1,48E-04	3,69E-05				9,09E-06		3,08E-07	3,02E-08					
3.2.8			7,41E-05	1,56E-05				1,12E-05		2,40E-07	8,02E-09					
3.2.9			5,84E-04	3,13E-04				7,69E-05		1,53E-04	4,01E-04					
3.2.10			4,57E-04	1,05E-04				4,20E-06		6,67E-07	5,35E-07					
3.2.11			2,68E-04	9,09E-05				2,38E-05		1,13E-07	1,60E-07					
3.2.12			2,84E-04	7,39E-05		2,69E-03	1,03E-03	9,30E-05		5,99E-08	2,37E-08					
3.2.13			1,97E-04	6,62E-05		7,94E-04	4,72E-04	2,89E-05		2,05E-07	2,98E-08					
3.2.14			2,54E-04	4,57E-05		1,00E-03	6,66E-04	5,38E-05		2,05E-07	1,90E-08					
3.2.15	5,04E-04	5,10E-04	4,98E-04	1,46E-04	1,91E-05	1,36E-03	1,66E-03	5,07E-05	8,44E-06	7,93E-08	4,33E-08	8,62E-07		2,19E-08		
3.2.16	2,96E-04	3,00E-04	3,21E-04	1,42E-04	2,87E-05	2,73E-04	4,12E-04	3,68E-05	1,75E-05	3,34E-07		1,72E-06		7,63E-07	5,06E-07	2,84E-06

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.3.1			8,33E-03	3,91E-05				7,53E-06		7,70E-07	3,74E-08					
3.3.2			1,22E-03	2,65E-05				1,23E-06		1,22E-07						
3.3.3			7,91E-04	1,62E-04				1,78E-05		3,35E-06	2,40E-08					
3.3.4			8,99E-04	3,07E-04				1,16E-05		1,61E-06	1,38E-08					
3.3.5			5,12E-04	3,07E-04				4,86E-05		1,19E-05	6,36E-05					
3.3.6			5,43E-04	1,03E-04				1,51E-05		1,11E-06	2,58E-07					
3.3.7			1,86E-04	4,47E-05				1,16E-05		4,19E-07	1,53E-07					
3.3.8			1,55E-04	5,31E-05				2,33E-05		4,35E-07	4,87E-07					
3.3.9			3,41E-04	1,80E-04				1,03E-04		7,37E-05	2,86E-04					
3.3.10			5,27E-04	3,07E-04				2,74E-04		3,18E-06	7,49E-06					
3.3.11			4,19E-04	2,79E-04				4,11E-05		2,34E-07	3,74E-07					
3.3.12			4,34E-04	3,07E-04		2,00E-04	1,94E-04	2,12E-04		3,68E-07	9,93E-07					
3.3.13			1,55E-04	1,27E-04		3,05E-04	1,48E-04	3,05E-05		2,51E-07	2,59E-07					
3.3.14			2,40E-04	7,29E-05		4,74E-04	2,52E-04	6,37E-05		2,65E-07	2,64E-07					
3.3.15	6,71E-04	6,81E-04	6,05E-04	3,67E-04	1,19E-04	3,65E-04	1,32E-03	1,53E-04	1,22E-05	2,56E-07	6,09E-07	3,47E-06		1,78E-06	2,72E-06	2,62E-06
3.3.16	1,63E-04	1,65E-04	1,67E-04	1,63E-04	8,06E-05	1,70E-04	1,18E-04	4,80E-05	8,82E-06	3,10E-07	2,66E-07	3,65E-06		2,28E-06	1,91E-06	4,33E-06

Table B 1 (Continued)

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.1.1		1,50E-03	5,59E-05				2,60E-06		9,72E-07	3,25E-07		3,17E-07			2,10E-07
3.1.2		1,17E-04	3,73E-05				1.5E-06		5,23E-07	5,42E-07		2,87E-07			
3.1.3		2,07E-04	4,97E-05				7.60E-07		2,80E-07	1,33E-07					
3.1.4		1,03E-04	1,21E-04				<7.6E-07		7,85E-07	2,09E-07					
3.1.5		3,44E-05	1,58E-04				1,37E-05			4,00E-04		4,91E-04			2,92E-04
3.1.6		1,38E-05	1,11E-04				<1.5E-06		3,36E-06	5,01E-06		4,53E-07			4,63E-06
3.1.6B		1,31E-05	3,42E-05				<1.5E-06		4,11E-06	2,25E-06		1,02E-06			2,49E-06
3.1.7		1,07E-05	4,97E-06				<1.5E-06		3,55E-07	2,09E-07					8,19E-07
3.1.8		8,95E-06	8,07E-06				9,92E-07		6,17E-07	2,21E-07					7,47E-07
3.1.9		4,82E-05	2,27E-04				4,58E-05			4,00E-04		3,58E-04			2,54E-04
3.1.10		4,13E-05	7,14E-05				1,98E-05		4,11E-05	2,09E-04		2,49E-04			1,32E-04
3.1.11		3,44E-05	4,66E-05				3,21E-06		4,86E-08	8,34E-08					
3.1.12		5,16E-05	6,52E-05				1.80E-06		1,64E-06	8,76E-07					1,35E-06
3.1.13		5,46E-06	9,63E-05				1,15E-07			8,43E-06					
3.1.14		3,08E-05	5,96E-05			1,98E-05	3,82E-07			1,16E-06					2,85E-06
3.1.15	4,45E-06	4,45E-06		3,08E-06	2,49E-06	2,23E-04	5,51E-10	6,26E-07	5,81E-08		9,98E-07	7,40E-07	3,09E-07	4,50E-07	9,36E-07
3.1.16	1,47E-05	4,93E-06		7,88E-07	7,64E-06	1,87E-04	1,59E-07	1,54E-06	4,76E-08		2,31E-06	3,25E-06	9,06E-07	6,95E-07	6,47E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.2.1		8,20E-04	3,69E-05				7,00E-07		4,10E-07	3,36E-07		4,15E-07			
3.2.2		2,37E-05	1,39E-05				1.4E-06		1,54E-07	1,68E-07		8,65E-08			1,34E-07
3.2.3		3,63E-05	2,05E-05						4,96E-07	4,59E-07					2,78E-07
3.2.4		2,52E-05	1,16E-05				7,00E-07		1,40E-07	3,52E-07					4,90E-07
3.2.5		3,79E-05	5,40E-05				2,52E-05			3,59E-04		2,46E-04			2,22E-04
3.2.6		9,31E-06	3,35E-06				<2.1E-06		9,24E-08	2,75E-07					2,88E-07
3.2.6B		6,78E-06	4,26E-06				<2.1E-06		1,34E-07	1,11E-07					
3.2.7		7,73E-06	3,98E-06				4,90E-07			2,98E-07					7,19E-07
3.2.8		6,94E-06	2,10E-06				1,19E-06		2,37E-08	5,35E-07		7,61E-07			4,25E-07
3.2.9		2,52E-05	1,92E-05				2,38E-05		1,21E-05	5,92E-05		3,84E-05			2,88E-05
3.2.10		6,47E-06	9,38E-06				<1.4E-06		8,04E-07	1,53E-06		1,66E-06			2,55E-06
3.2.11		1,45E-05	8,81E-06				3,57E-06		6,16E-08	1,80E-07					5,23E-07
3.2.12		6,94E-06	5,97E-06				3,99E-06		3,76E-08	1,83E-07					4,25E-07
3.2.13		5,68E-06	7,24E-06				6,50E-07								
3.2.14		9,38E-06	9,29E-06			2,06E-05	1,54E-06								
3.2.15	3,40E-06	3,15E-06			8,01E-06	9,90E-05	1,14E-06	2,48E-07	4,90E-08		4,10E-07	4,86E-07	1,20E-07	2,14E-07	5,91E-07
3.2.16	1,55E-05	4,95E-06		1,11E-06	4,22E-06	5,50E-05	7,26E-07	1,24E-07	4,24E-09		1,11E-06	3,00E-06	2,89E-07	1,75E-07	

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.3.1		8,06E-04	6,70E-06				<2.7E-06		1,17E-06	1,27E-06		6,12E-07			7,37E-07
3.3.2		8,37E-05	4,75E-06				1.37E-06		3,35E-07	3,29E-07		2,11E-07			1,92E-07
3.3.3		5,43E-05	1,15E-05				1.37E-06		2,31E-07	1,72E-07					
3.3.4		3,88E-05	2,40E-05				1.37E-06		1,47E-07	9,73E-08		1,36E-06			
3.3.5		2,02E-05	2,29E-05				2,47E-06			6,74E-05		8,50E-05			3,45E-05
3.3.6		9,61E-06	8,38E-06				2,12E-06			1,38E-06					9,94E-07
3.3.7		6,20E-06	3,35E-06				<2.1E-06			3,74E-07					8,01E-07
3.3.8		1,01E-05	5,59E-06				1,92E-06		1,36E-07	7,49E-07					1,38E-06
3.3.9		8,76E-06	4,80E-06				5,34E-06		4,35E-06	2,77E-05		2,23E-05			1,43E-05
3.3.10		3,57E-05	1,76E-04				2,88E-05		3,01E-05	3,52E-04		3,74E-04			2,28E-04
3.3.11		2,17E-05	2,79E-05				2,67E-06			7,86E-07					2,05E-06
3.3.12		1,44E-05	3,07E-05						2,68E-07	3,33E-06					8,65E-06
3.3.13		4,79E-06	1,50E-05				6,30E-07			5,11E-07					
3.3.14		7,18E-06	7,21E-06			7,11E-06	1,16E-06			2,07E-07					
3.3.15	6,39E-06	9,02E-06		8,19E-07	4,42E-06	8,74E-05	2,92E-06	2,07E-07	1,95E-08		7,05E-07	9,88E-07	3,93E-07	5,85E-07	1,06E-06
3.3.16	5,93E-06	2,82E-06		9,45E-07	2,61E-06	2,72E-05	1,05E-06	5,94E-08	3,52E-09		7,41E-07	9,58E-07	3,85E-07	3,12E-07	2,02E-07

Table B 1 (Continued)

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.1.1		6,20E-05	1,40E-05				1,15E-05		1,03E-05	1,13E-05		1,74E-05			1,10E-05
3.1.2		2,93E-05	1,74E-05				1,68E-05		1,53E-05	1,75E-05		3,09E-05			2,03E-05
3.1.3		2,75E-05	2,35E-06				2,06E-06		1,38E-06	1,29E-06		3,62E-06			2,67E-06
3.1.4		4,30E-05	2,17E-05				1,53E-05		1,72E-05	2,29E-05		2,91E-05			2,35E-05
3.1.5		2,24E-05	2,61E-06				1,60E-06		2,62E-06	2,88E-06		5,28E-06			2,70E-06
3.1.6		3,10E-05	9,94E-06				1,15E-05		1,16E-05	1,79E-05		1,66E-05			1,49E-05
3.1.6B		8,61E-06	1,89E-07				<6.9E-07			3,17E-06		7,92E-07			4,63E-06
3.1.7		8,61E-05	1,37E-05				2,29E-07			2,79E-06					3,91E-06
3.1.8		6,20E-05	2,73E-05				3,82E-07		3,36E-07	3,50E-06					2,21E-06
3.1.9		1,69E-05	5,28E-06				2,14E-06		5,61E-07	7,93E-07					9,96E-07
3.1.10		1,43E-04	4,35E-06				1,83E-06		3,93E-05	8,76E-06					9,96E-06
3.1.11		1,02E-05	2,70E-06				1,98E-06		1,50E-06	8,34E-07					5,34E-07
3.1.12		2,93E-04	4,04E-04				3,73E-04		4,67E-04	2,88E-04		3,13E-04			2,70E-04
3.1.13		8,30E-06				3,04E-07	7,63E-07		4,56E-07	2,75E-06					
3.1.14		7,87E-06	1,11E-06			<1.3E-06	5,11E-07			1,42E-06					
3.1.15	7,83E-05	4,08E-05		1,04E-06	1,20E-06	5,31E-06	5,51E-06	3,28E-06	6,08E-07	1,09E-06	1,70E-06	8,98E-07	7,38E-07	7,86E-07	1,05E-06
3.1.16	1,62E-05	1,04E-05			4,11E-06	1,05E-05	6,86E-06	2,58E-06	4,69E-07	1,38E-06	2,64E-06	1,56E-06	1,42E-06	1,36E-06	1,80E-06

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.2.1		2,21E-05	2,24E-05				2,38E-05		2,05E-05	1,80E-05		9,69E-05			2,16E-05
3.2.2		3,47E-06	3,13E-06				3,99E-06		2,22E-06	2,87E-06		5,54E-06			2,42E-06
3.2.3		3,31E-06	2,81E-06				3,50E-06		1,88E-06	1,37E-06		1,25E-05			3,20E-06
3.2.4		5,36E-06	1,76E-06				1,75E-06		1,63E-06	2,36E-06		5,34E-06			2,68E-06
3.2.5		5,68E-06	2,81E-06				6,92E-06		3,59E-06	2,87E-06		5,54E-06			3,27E-06
3.2.6		1,89E-06	3,41E-07				5,59E-07		5,82E-07	3,73E-07		1,25E-06			4,25E-07
3.2.6B		1,47E-05	1,65E-05				1,47E-05		1,88E-05	1,26E-05		1,90E-05			1,50E-05
3.2.7		8,32E-06	1,34E-06				9,09E-07		1,40E-06	2,06E-06		3,04E-06			9,80E-07
3.2.8		1,74E-05	2,84E-06				6,99E-07		4,62E-07	6,11E-07					
3.2.9		2,37E-05	1,76E-06				4,48E-05		2,22E-06	1,83E-06					2,75E-06
3.2.10		2,68E-06	2,41E-07				2,38E-06		3,25E-07	5,35E-07					6,54E-07
3.2.11		5,68E-06	5,11E-07				1,12E-06		1,88E-07	6,11E-07					8,17E-07
3.2.12		4,10E-06	1,53E-07				<4.2E-08			1,15E-06					2,71E-06
3.2.13		1,01E-05				1,31E-06	1,96E-07		4,96E-08	3,29E-08					
3.2.14		1,77E-05	1,28E-06			<1.2E-05	4,20E-07			2,66E-07					
3.2.15	5,27E-05	1,91E-04		1,20E-05	3,09E-06	4,48E-06	3,95E-06	4,42E-07	1,71E-06	1,65E-06	2,44E-06	3,16E-06	1,77E-06	1,75E-06	2,38E-06
3.2.16	6,69E-06	2,52E-05		3,96E-06	1,77E-06	9,91E-07	1,14E-06	2,15E-07	3,06E-07	3,43E-07	1,83E-06	3,18E-06	8,57E-07	4,79E-07	2,66E-07

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.3.1		6,82E-06	2,29E-06				6,85E-07		1,52E-06	1,24E-06		2,59E-06			
3.3.2		5,74E-06	3,91E-06				4,93E-06		2,68E-06	2,17E-06		5,78E-06			4,81E-06
3.3.3		2,33E-06	8,94E-07				1,85E-06		6,53E-07	4,49E-07		1,39E-06			
3.3.4		1,13E-05	1,90E-06				3,29E-06		1,16E-06	1,01E-06		3,74E-06			1,67E-06
3.3.5		1,29E-05	5,87E-07				4,79E-07		2,68E-07	4,49E-07					
3.3.6		2,17E-05	1,68E-06				8,22E-07		1,04E-06	3,59E-07		1,80E-06			1,86E-06
3.3.7		1,86E-05	1,23E-06				8,22E-07		6,03E-07	1,50E-06		2,45E-06			2,82E-06
3.3.8		2,48E-05	4,47E-06				1,37E-06		4,35E-07	1,42E-06					2,76E-06
3.3.9		1,50E-05	5,87E-06				1,37E-06		4,35E-07	1,20E-06		1,22E-05			1,03E-06
3.3.10		3,10E-05	1,79E-06				6,85E-06		2,01E-06	5,24E-06		8,16E-06			9,29E-06
3.3.11		9,30E-06	1,82E-06				2,26E-06		2,85E-07	5,61E-07					8,65E-07
3.3.12		8,06E-06	5,59E-07				<4.1E-08			7,12E-07					1,99E-06
3.3.13		1,08E-05				1,19E-06	3,01E-07		7,20E-08	2,40E-07					
3.3.14		5,94E-06	1,38E-06			2,37E-06	5,48E-07			1,38E-07					
3.3.15	3,20E-05	9,85E-05		3,45E-05	1,27E-06	2,81E-06	4,60E-06	6,41E-07	6,99E-07	3,23E-06	4,79E-06	5,43E-06	3,53E-06	4,35E-06	5,36E-06
3.3.16	4,57E-06	1,47E-05		8,31E-06	9,39E-07	5,59E-07	1,88E-06	2,13E-07	4,06E-07	8,45E-07	1,73E-06	1,77E-06	1,44E-06	1,19E-06	1,77E-06

Table B 2. Selected release fractions: Series 3.2326 corrosion tests

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.23.1			9,24E-03	1,52E-03				6,37E-04		1,87E-05	5,00E-07					2,68E-06
3-23.2	4,03E-03	4,07E-03	8,51E-03	2,31E-03	3,67E-04	4,17E-03	2,89E-03	6,69E-04	5,74E-04	5,66E-06	5,35E-07	2,20E-06	1,01E-05	7,27E-07	1,56E-06	4,83E-06
3.23.3	3,57E-04	3,62E-04	3,38E-04	2,50E-04	2,57E-04	4,57E-04	2,80E-04	2,99E-04	2,00E-04	3,06E-06	6,33E-07		6,19E-06		4,53E-07	
3.23.4	8,27E-05	8,37E-05	2,72E-04	2,26E-05	8,09E-04	3,69E-03		2,66E-06	2,66E-06	3,87E-07	4,24E-08	4,28E-07	5,48E-07	5,62E-07	7,60E-07	5,35E-06
3.24.1			1,25E-02	1,64E-03				7,45E-04		1,16E-05	1,57E-06					6,42E-06
3.24.2	4,60E-03	4,65E-03	1,25E-02	3,10E-03	1,91E-03	7,27E-03	4,78E-03	1,63E-03	7,01E-04	3,65E-06	2,97E-06	3,91E-06	7,49E-06	2,97E-06	3,07E-06	2,27E-05
3-24.3	3,60E-04	3,64E-04	4,96E-04	2,29E-04	3,86E-04	4,46E-04	3,26E-04	1,22E-04	1,33E-04	3,61E-06	5,02E-07	7,16E-07	6,80E-07		2,12E-06	1,06E-06
3.24.4	1,50E-04	1,52E-04	3,38E-04	4,62E-05	3,37E-04	2,68E-03	5,63E-06	3,71E-06	1,94E-06	4,80E-07	6,04E-08	4,07E-07	2,24E-07	3,88E-07	5,94E-07	5,21E-06
3.24.5	1,05E-04	1,07E-04	1,70E-04	4,52E-05	2,24E-04	8,47E-04	5,72E-06	2,45E-07	4,94E-06	1,02E-06		1,07E-06	8,18E-07	8,09E-07	9,79E-07	6,85E-06
3.25.1			1,05E-02	1,84E-03				1,02E-03		1,39E-05	3,86E-06					1,66E-05
3.25.2	4,34E-03	4,39E-03	1,03E-02	2,67E-03	2,22E-03	5,44E-03	3,96E-03	2,01E-03	8,47E-04	5,01E-06	1,39E-06	3,29E-05	1,45E-04	3,59E-05	4,17E-05	7,76E-05
3.26.1			4,67E-03	1,10E-03				2,02E-07		1,28E-04	4,10E-06					7,83E-06
3.26.2	4,38E-03	4,43E-03	5,67E-03	1,82E-03	8,51E-04	1,56E-03	1,01E-02	3,23E-07	4,84E-05	5,49E-05	4,82E-06	4,79E-04	5,45E-05	1,63E-04	2,33E-04	3,08E-04

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.23.1															
3-23.2	9,96E-05	1,89E-04	6,81E-05	1,17E-05	7,37E-05	3,76E-04	1,94E-05	1,35E-05	5,29E-07	2,56E-06	2,11E-05	3,94E-05	5,22E-06	2,96E-06	1,76E-05
3.23.3	6,80E-04	7,93E-05		5,37E-05	2,45E-05	3,33E-05	8,73E-06	3,92E-06	7,32E-07		1,60E-04	3,47E-04	3,47E-05	1,81E-05	1,00E-05
3.23.4	2,47E-04			3,71E-05	7,93E-05		3,91E-07	1,70E-06	3,23E-07		3,98E-05	1,16E-04	9,69E-06	5,95E-06	4,60E-07
3.24.1															
3.24.2	1,12E-04	2,44E-04	8,64E-05	4,07E-05	1,14E-04	5,53E-04	4,29E-05	1,07E-05	2,58E-07	2,40E-06	8,08E-06	1,29E-05	2,19E-06	1,57E-06	
3-24.3	6,76E-04	1,35E-05			1,55E-05	5,11E-05	3,61E-06	3,30E-06	4,41E-07		1,05E-04	2,44E-04	2,26E-05	1,25E-05	5,90E-06
3.24.4	1,91E-04	1,20E-05		1,94E-05	4,52E-05		1,10E-07	6,04E-09	2,34E-07		3,03E-05	6,04E-05	7,20E-06	3,83E-06	
3.24.5	2,55E-04	7,49E-06		2,96E-05	2,48E-05		9,98E-08		4,37E-08		3,92E-05	9,25E-05	1,03E-05	5,67E-06	
3.25.1															
3.25.2		4,14E-04	2,57E-04			1,32E-04	7,70E-05								1,76E-05
3.26.1															
3.26.2		5,33E-04	2,16E-03			5,33E-04	4,74E-06		8,27E-06	1,65E-04					4,24E-04

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.23.1															
3-23.2	2,06E-04	1,12E-03	4,03E-05	1,07E-04	6,63E-05	2,46E-05	6,75E-06	3,34E-06	1,26E-05	3,11E-05	2,70E-05	6,56E-05	2,12E-05	2,49E-05	2,65E-05
3.23.3	3,33E-05	1,39E-05		9,74E-05	1,43E-05		8,34E-07		6,68E-07	1,42E-06	1,73E-05	2,81E-05	4,07E-06	3,62E-06	1,06E-05
3.23.4	3,06E-05	8,25E-06		9,74E-05	1,46E-05	2,79E-06	3,59E-06	9,18E-06	6,12E-06		5,25E-05	3,79E-05	1,62E-05	1,18E-05	1,30E-05
3.24.1															
3.24.2	3,21E-04	2,18E-03	1,09E-04	5,76E-04	7,28E-05	2,12E-05	1,03E-05	3,28E-05	1,28E-05	2,80E-05	2,78E-05	4,91E-05	1,82E-05	2,07E-05	1,99E-05
3-24.3		2,07E-05		1,26E-05	3,07E-06	1,10E-06	3,89E-07	7,35E-07	1,50E-07	1,13E-06	6,88E-06	1,13E-05	1,88E-06	2,11E-06	5,65E-06
3.24.4	2,38E-05	8,45E-06		4,15E-05	1,05E-05	2,55E-06	1,17E-06	2,64E-06	6,76E-06		8,50E-05	8,25E-05	2,77E-05	2,28E-05	2,05E-05
3.24.5	4,37E-06	6,63E-06		2,05E-05	5,57E-06		1,03E-06	7,23E-07	2,82E-06		3,97E-05	3,17E-05	1,11E-05	6,70E-06	1,66E-06
3.25.1															
3.25.2		6,48E-04	1,44E-04			1,58E-05	2,84E-05		3,47E-05	2,89E-05					
3.26.1															
3.26.2		5,35E-03	4,43E-04			4,19E-05	7,96E-05		2,20E-05	5,03E-05					

Table B 3. Selected release fractions: Series 7 corrosion tests

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
7.1.1			8,49E-03	3,85E-04			< 6,0E-05	1,58E-05		2,15E-06	1,58E-06					6,38E-06
7.1.2			5,52E-04	1,29E-04			2,77E-04	1,96E-05		1,14E-06	6,43E-07					3,06E-06
7.1.3			4,29E-04	7,75E-05			2,13E-04	<1.8E-06		1,25E-05	2,74E-07					
7.2.1			6,87E-03	3,33E-04			9,86E-05	2,29E-05		2,92E-06	1,41E-06					3,58E-06
7.2.2			9,87E-04	1,08E-04			2,17E-04	1,70E-05		9,74E-07	4,41E-07					2,10E-06
7.2.3			4,38E-04	2,94E-05			1,26E-04	<1.0E-08		4,38E-06						
7.2.4	4,13E-04	4,12E-04	3,50E-04	1,04E-04	7,93E-06	7,80E-05	1,49E-03	<4,7E-07	1,44E-05	2,05E-06	5,39E-07	1,59E-06	4,84E-07	4,19E-07	2,98E-07	6,40E-07
7.3.1			8,08E-03	4,24E-04			< 6,0E-05	1,93E-05		3,48E-06	1,87E-06					6,99E-06
7.3.2			4,80E-04	1,02E-04			1,44E-04	1,25E-05		9,45E-07	4,52E-07					2,01E-06
7.3.3			3,93E-04	2,40E-04			6,61E-04	3,56E-05		6,24E-07	2,28E-07					
7.4.1			6,16E-03	3,30E-04			9,75E-05	2,19E-05		2,90E-06	1,58E-06					7,66E-06
7.4.2			4,67E-04	7,69E-05			2,24E-04	1,50E-05		6,28E-07	2,81E-07					1,45E-06
7.4.3			4,61E-04	1,33E-04			1,11E-03	5,84E-05		6,04E-07	1,46E-07					
7.4.4			6,80E-04	4,13E-05			2,05E-03	1,36E-05		8,19E-07						
7.4.5	6,16E-04	6,15E-04	6,55E-04	4,26E-04	9,46E-05	1,08E-03	1,59E-03	7,94E-05	2,72E-05	5,05E-07	1,26E-07	5,14E-07	1,53E-07	4,18E-07	2,75E-07	5,37E-07
7.5.1			7,86E-03	3,95E-04			2,40E-04	2,68E-05		3,23E-06	1,93E-06					7,42E-06
7.5.2			4,37E-04	1,13E-04			1,40E-04	1,73E-05		9,45E-07	7,23E-07					3,10E-06
7.5.3			8,69E-04	2,34E-04			2,96E-03	1,15E-04		1,00E-06	6,45E-07					
7.5.4	1,07E-03	1,07E-03	1,18E-03	4,31E-04	7,08E-05	1,51E-03	2,09E-03	8,17E-05	4,24E-05	6,29E-07	3,30E-07	1,42E-06		1,68E-06	1,37E-06	2,55E-06
7.6.1			7,64E-03	3,67E-04			6,77E-04	2,99E-05		3,73E-06	1,39E-06					5,68E-06
7.6.2			4,80E-04	1,13E-04			6,99E-05	1,92E-05		7,21E-07	6,02E-07					2,45E-06
7.6.3			4,72E-04	1,89E-04			3,10E-03	4,71E-05			1,51E-07					
7.6.4	8,13E-04	8,11E-04	9,16E-04	3,56E-04	9,05E-05	1,57E-03	2,04E-03	7,21E-05	2,64E-05	3,90E-07	1,07E-07	1,95E-06	2,40E-06	8,22E-07	4,64E-07	1,94E-06
7.7.1			8,73E-03	2,82E-04			3,61E-04	1,16E-05		3,48E-07	2,95E-08					2,58E-07
7.7.2			2,18E-04	1,95E-04			7,03E-05	7,69E-06		7,46E-07	1,81E-08					
7.7.3			8,95E-05	3,73E-05			2,32E-05	4,66E-05		1,67E-07	2,60E-07					
7.8.1			8,73E-03	3,11E-04			3,61E-04	9,33E-06		1,17E-07	2,83E-08					4,10E-07
7.8.2			1,51E-04	5,37E-05			3,20E-06	3,08E-06		2,16E-08	3,49E-09					
7.8.3			4,89E-04	2,97E-05			4,96E-06	2,31E-06								
7.9.1			1,03E-02	3,61E-04			1,38E-04	8,49E-06			8,24E-09					
7.9.2			2,36E-04	6,11E-05			5,34E-06	9,43E-07		1,61E-08	4,59E-08					
7.9.3			1,67E-04	5,28E-05			5,03E-06	1,37E-06								
7.10.1			9,52E-03	3,38E-04			7,94E-05	7,62E-06			9,32E-09					
7.10.2			5,84E-04	2,80E-05			4,91E-06	1,90E-07		1,08E-07	8,33E-08					
7.10.3			1,81E-04	8,24E-05			<2.4E-06	1,22E-06								
7.11.1			8,58E-03	3,61E-04			2,95E-04	9,91E-06			5,88E-09					
7.11.2			7,08E-04	1,69E-05			<1.0E-06	2,83E-07		1,07E-08	1,35E-08					
7.11.3	3,68E-04	3,67E-04	3,34E-04	2,05E-04	5,90E-04	1,05E-03	5,75E-06	1,06E-06	2,33E-07	6,44E-08		1,54E-06	1,90E-06	5,98E-07	3,28E-07	3,96E-06
7.12.1			4,98E-03	3,08E-04			1,19E-04	1,60E-05		1,28E-06	8,33E-08					
7.12.2			1,32E-03	4,48E-05			2,46E-05	2,15E-05		9,36E-09	1,61E-08					1,99E-07
7.12.3	2,34E-04	2,33E-04	1,28E-03	1,03E-04	3,32E-04	9,04E-04	1,03E-05	1,41E-06	5,85E-07	4,78E-08		8,33E-07	9,64E-07	3,28E-07	1,22E-07	3,04E-06
7.13.1			1,20E-02	2,41E-05			1,67E-04	<3.0E-08								
7.13.2			3,41E-04	5,15E-04			5,27E-05	1,60E-05		2,38E-08	1,50E-08					
7.13.3			1,02E-04	2,61E-05			<8.0E-06	<4.0E-08								
7.13.4			8,28E-05	9,85E-06			<2.5E-06	<2.0E-07			6,25E-07					
7.13.5	4,48E-05	4,47E-05	3,55E-05	1,39E-05	6,17E-05	3,18E-05	4,32E-06	5,97E-07	3,50E-08	1,14E-07		2,86E-08	8,49E-07	6,30E-07	2,97E-07	6,37E-07
7.14.1			9,46E-03	3,21E-05			6,19E-05	<3.0E-08								
7.14.2			2,25E-04	3,99E-04			3,18E-05	9,90E-06		1,64E-08	2,53E-09					
7.14.3			1,24E-04	2,41E-05			<8.0E-06	<2.0E-08								
7.14.4	1,89E-04	1,89E-04	1,54E-04	1,26E-04	1,52E-04	3,08E-04	1,96E-04	2,55E-05		5,41E-08						4,59E-07

Table B 3. (Continued)

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
7.1.1		2,12E-04	3,30E-05				3,36E-06		3,38E-06	4,68E-06		1,54E-06			6,38E-06
7.1.2		1,74E-05	2,17E-05				1,68E-07		3,38E-07	1,99E-06					4,26E-06
7.1.3		2,40E-05	1,48E-04			6,59E-07	1,40E-07		2,63E-06	1,79E-05					2,01E-05
7.2.1		1,85E-04	2,78E-05				3,68E-06		3,41E-06	3,71E-06		1,00E-06			7,73E-06
7.2.2		2,58E-05	9,44E-06				2,26E-07			1,35E-06					2,10E-06
7.2.3		7,68E-05	9,75E-05			1,96E-06	2,26E-07			4,36E-07					
7.2.4		1,73E-05													
7.3.1		2,18E-04	3,39E-05				3,56E-06			3,61E-06		1,98E-07			6,11E-06
7.3.2		1,22E-05	8,19E-06				2,31E-07		1,59E-07	1,14E-06					1,88E-06
7.3.3		1,36E-05	1,13E-05			2,56E-06	1,11E-06		8,71E-07	1,04E-06					3,39E-06
7.4.1		1,53E-04	2,20E-05				2,80E-06			3,16E-06		7,14E-07			5,53E-06
7.4.2		1,30E-05	6,32E-06				2,24E-07		2,25E-07	1,17E-06					2,26E-06
7.4.3		1,54E-05	1,05E-05				1,78E-06			4,22E-07					
7.4.4		3,89E-05	1,27E-05			5,33E-05	4,67E-07			5,23E-07					
7.4.5		1,37E-05													
7.5.1		1,88E-04	2,82E-05				3,75E-06		3,23E-06	4,40E-06		1,19E-06			5,24E-06
7.5.2		1,03E-05	9,60E-06				2,88E-07		3,48E-07	1,87E-06		1,47E-07			2,79E-06
7.5.3		2,47E-05	2,44E-05			6,12E-05	2,57E-06			1,36E-06					
7.5.4		3,41E-05													
7.6.1		1,86E-04	2,80E-05				6,06E-06		1,87E-06	3,55E-06		7,34E-07			5,68E-06
7.6.2		1,14E-05	8,47E-06				2,88E-07		5,47E-07	1,20E-06					2,84E-06
7.6.3		1,65E-05	1,93E-05			8,94E-05	1,35E-06			2,87E-07					
7.6.4		2,42E-05													
7.7.1		3,06E-04	2,77E-05				2,50E-06		2,74E-06	2,65E-06		1,47E-06			1,57E-06
7.7.2		7,21E-06	2,03E-05				1,54E-07		2,31E-07	4,70E-07		2,43E-07			7,86E-07
7.7.3		4,08E-06	2,06E-06			3,68E-07	3,12E-06		5,72E-07	9,52E-07					
7.8.1		2,84E-04	2,74E-05				3,56E-06		4,73E-06	3,43E-06		1,53E-06			1,35E-06
7.8.2		5,68E-06	7,63E-06				1,15E-07		6,97E-08	1,20E-07		1,64E-07			2,01E-07
7.8.3		1,74E-05	2,00E-06				5,38E-07			4,70E-08					
7.9.1		3,22E-04	3,06E-05				1,51E-06		2,24E-06	1,71E-06		7,22E-07			8,15E-07
7.9.2		7,08E-06	6,67E-06				1,13E-07		5,85E-08	2,41E-07					3,39E-07
7.9.3		9,27E-06	3,92E-06				1,17E-06			3,24E-07					
7.10.1		2,60E-04	2,32E-05				2,00E-06		2,14E-06	1,61E-06		7,82E-07			8,66E-07
7.10.2		2,60E-05	5,32E-06				1,14E-07		4,68E-07	1,13E-06		1,51E-06			1,65E-06
7.10.3		8,20E-06	6,53E-06			<4.0E-06	5,24E-07		3,00E-07	4,98E-07					
7.11.1		3,00E-04	2,78E-05				2,36E-06		2,29E-07	2,88E-07		2,50E-07			3,39E-07
7.11.2		4,51E-05	3,89E-06				3,40E-07		1,97E-07	4,59E-07		6,67E-07			5,15E-07
7.11.3															
7.12.1		1,39E-04	2,24E-05				3,52E-06		4,43E-07	8,33E-07		6,15E-07			
7.12.2		9,09E-05	7,28E-06				1,52E-06		1,18E-06	2,38E-06		1,73E-06			2,25E-06
7.12.3		3,64E-05													8,70E-06
7.13.1		7,50E-04	5,29E-06				3,00E-06		2,35E-06			6,47E-07			6,36E-07
7.13.2		1,09E-05	7,06E-05				3,60E-07		9,30E-09	9,38E-08					3,95E-07
7.13.3		3,39E-06	2,25E-06				<2.0E-07								
7.13.4		5,34E-06	1,08E-05			<4.2E-06	2,00E-07		5,32E-06	3,29E-05					2,93E-05
7.13.5		1,02E-05													
7.14.1		7,88E-04	5,54E-06				8,81E-07		4,87E-07	4,07E-07		1,51E-07			
7.14.2		7,43E-06	5,54E-05				1,58E-07		4,36E-08	5,86E-08					
7.14.3		4,35E-06	2,14E-06			2,06E-06	<4.0E-08								
7.14.4		4,92E-06													

Table B 3. (Continued)

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
7.1.1		4,67E-05	1,13E-05			2,07E-04	1,21E-05		2,42E-05	2,22E-05		1,76E-05			1,62E-05
7.1.2		3,40E-06	3,02E-07			<6.0E-05	2,34E-07		5,31E-07	1,17E-06		5,49E-07			1,19E-06
7.1.3		7,39E-05				1,25E-05	6,54E-06		4,90E-05	1,54E-05					3,77E-05
7.2.1		3,22E-05	5,00E-06			9,86E-05	4,72E-06		5,60E-06	5,06E-06		5,56E-06			6,01E-06
7.2.2		4,94E-06	4,44E-07			<6.0E-05	4,25E-07		5,36E-07	4,88E-07		6,11E-07			6,87E-07
7.2.3		1,45E-04	4,78E-06			1,10E-06	3,87E-06		1,55E-06	1,56E-06					
7.2.4	1,08E-05	2,06E-05	6,50E-06	5,29E-06	6,19E-06	5,62E-06	5,72E-06	5,51E-06	4,76E-06	5,13E-06	6,57E-06	6,69E-06	5,98E-06	4,22E-06	4,40E-06
7.3.1		3,93E-05	3,95E-06			1,20E-04	3,85E-06		4,98E-06	3,73E-06		3,37E-06			4,24E-06
7.3.2		3,28E-06	2,23E-07			<6.0E-05	1,92E-07		2,49E-07	4,94E-07		1,39E-07			5,24E-07
7.3.3		1,78E-05					2,69E-07		5,92E-07	8,73E-07					
7.4.1		2,76E-05	7,69E-06			5,85E-05	9,35E-06		1,21E-05	9,36E-06		8,24E-06			6,38E-06
7.4.2		3,40E-06	4,67E-07			<6.0E-05	5,14E-07		6,52E-07	8,19E-07		6,04E-07			8,09E-07
7.4.3		6,86E-05	3,74E-07			3,90E-04	2,80E-06		3,21E-06	1,70E-06					
7.4.4		4,14E-05	1,62E-06			6,22E-06	3,74E-07		5,53E-07	8,65E-07					
7.4.5	3,13E-05	1,02E-04		1,75E-05	3,75E-06	8,93E-07	8,28E-07	1,24E-07	1,97E-07	5,43E-07	2,18E-06	2,21E-06	9,40E-07	6,17E-07	8,58E-07
7.5.1		8,52E-05	3,67E-05			7,99E-05	4,42E-05		7,21E-05	5,30E-05		4,52E-05			4,06E-05
7.5.2		2,40E-06	4,24E-07			<6.0E-05	4,33E-07		6,97E-07	8,43E-07		6,21E-07			1,00E-06
7.5.3		1,11E-04	7,12E-06			4,62E-06	4,52E-06		4,65E-06	4,42E-06					
7.5.4	2,02E-04	1,56E-04		5,94E-06	1,13E-06	6,79E-07	4,83E-06	1,25E-06	6,35E-07	4,05E-06	4,18E-06	9,01E-07	2,64E-06	2,47E-06	4,11E-06
7.6.1		5,46E-05	1,67E-05			<6.0E-05	2,21E-05		3,23E-05	2,53E-05		2,03E-05			1,83E-05
7.6.2		2,84E-06	1,27E-07			<6.0E-05	1,92E-07			4,70E-07					4,24E-07
7.6.3		3,43E-04	1,30E-05			4,76E-06	2,31E-06		3,11E-06	4,81E-06					
7.6.4	1,71E-05	5,45E-05		1,03E-06	2,07E-06	8,30E-07	7,00E-07	1,46E-07	2,42E-07	3,34E-07	1,63E-06	2,00E-06	6,25E-07	4,24E-07	5,35E-07
7.7.1		1,18E-04	5,08E-05			1,40E-04	6,06E-05		1,32E-04	1,14E-04		7,34E-05			6,99E-05
7.7.2		7,42E-06	2,03E-06			<6.0E-05	9,62E-07		3,23E-06	2,53E-06		2,09E-06			2,97E-06
7.7.3		2,86E-06				2,65E-06	1,06E-06		2,40E-06	2,77E-06					2,50E-06
7.8.1		7,42E-05	1,21E-05			8,02E-05	1,15E-05		1,79E-05	1,63E-05		1,41E-05			1,40E-05
7.8.2		3,71E-06	5,37E-07			<6.0E-05	3,37E-07		5,97E-07	5,60E-07		3,84E-07			6,99E-07
7.8.3		6,53E-06	6,38E-06			<8.0E-06	7,69E-07		1,64E-06	7,59E-07					
7.9.1		4,08E-05	2,17E-05			5,92E-05	2,45E-05		3,41E-05	3,88E-05		2,89E-05			2,62E-05
7.9.2		4,08E-06	1,86E-06			<6.0E-05	1,75E-06		3,41E-06	2,59E-06		2,17E-06			2,23E-06
7.9.3															
7.10.1		7,79E-05	1,23E-05			1,79E-04	1,30E-05		2,36E-05	1,43E-05		1,51E-05			1,26E-05
7.10.2		5,84E-06	3,64E-07			<6.0E-05	2,86E-07		4,43E-07	2,98E-07		3,58E-07			3,94E-07
7.10.3		2,42E-05	9,44E-06			6,17E-06	8,29E-06		1,29E-05	1,35E-05					9,70E-06
7.11.1		1,03E-04	2,50E-05			1,77E-04	2,74E-05		4,14E-05	3,18E-05		3,00E-05			2,66E-05
7.11.2		8,15E-06	7,50E-07			<6.0E-05	8,02E-07		9,74E-07	7,06E-07		7,78E-07			9,87E-07
7.11.3	8,74E-06	1,04E-05		1,24E-05	7,82E-06	4,31E-06	9,43E-06	8,09E-06	8,65E-06	8,41E-06	1,21E-05	1,29E-05	9,86E-06	7,25E-06	5,69E-06
7.12.1		9,09E-04	3,92E-05			1,79E-04	3,33E-05		6,65E-05	3,39E-05		4,97E-05			4,33E-05
7.12.2						<6.0E-05									
7.12.3	2,28E-05	9,59E-05	2,93E-05	3,95E-05	2,59E-05	1,79E-05	2,49E-05	2,10E-05	3,48E-05	5,08E-05	3,49E-05	3,72E-05	3,20E-05	2,25E-05	2,83E-05
7.13.1		1,14E-03	9,12E-04			9,62E-04	1,26E-03		1,32E-03	1,13E-03		1,00E-03			1,05E-03
7.13.2		7,50E-06	1,50E-05			<6.0E-05	4,20E-06		6,72E-06	4,38E-06		4,47E-06			5,00E-06
7.13.3		2,32E-06	7,68E-07			<8.0E-06	8,00E-07		1,61E-06	5,41E-07					
7.13.4		3,97E-05	7,18E-06			4,17E-06	6,20E-06		9,33E-06	9,94E-06					7,77E-06
7.13.5	6,64E-06	9,41E-06			4,63E-06	2,85E-06	3,70E-06	3,82E-06	5,56E-06	5,71E-06	5,36E-06	5,97E-06	4,69E-06	3,24E-06	4,80E-06
7.14.1		5,86E-05	1,14E-05			<6.0E-05	1,25E-05		1,92E-05	1,60E-05		1,45E-05			1,40E-05
7.14.2		1,28E-05	1,11E-05			<6.0E-05	5,20E-06		7,44E-06	4,88E-06		6,40E-06			6,31E-06
7.14.3		3,78E-06	1,85E-06			<4.1E-04	<1.0E-06		2,21E-06	9,20E-07					
7.14.4	1,51E-05	4,90E-05			4,73E-06	3,79E-07	1,01E-06	3,01E-07	5,52E-07	7,02E-09	1,93E-06	2,17E-06	9,51E-07	6,84E-07	1,07E-06

Table B 4. Selected release fractions: Series 11 corrosion tests

FUEL SPECIMEN 11.1

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.1.1	1,18E-03	6,74E-04	2,33E-03	5,66E-05	1,06E-04	6,23E-05	4,89E-05	1,69E-05	1,28E-05	3,24E-06		1,65E-07	6,98E-07	1,24E-07	2,11E-07	1,52E-06
11.1.2	8,36E-04	5,07E-04	1,26E-03	1,77E-04	3,51E-04	2,99E-05	2,65E-05	1,49E-05	1,80E-06	3,00E-06		4,21E-07	1,00E-06	8,75E-08	1,51E-07	3,68E-06
11.1.3	1,43E-04	1,23E-04	1,31E-04	9,22E-05	2,37E-04	4,00E-05	6,27E-05	9,26E-06	5,00E-07	1,38E-06						
11.1.4	1,64E-04	1,34E-04	1,48E-04	6,90E-05	1,79E-04	1,21E-04	2,51E-04	2,71E-05	5,90E-06	2,68E-06		1,75E-06	1,11E-06		8,84E-07	1,83E-06
11.1.5	1,67E-04	1,45E-04	1,51E-04	3,40E-05	1,58E-04	2,41E-04	5,41E-04	1,01E-05	1,03E-06	5,91E-07		3,72E-08	5,55E-07	2,05E-07	2,20E-07	
11.1.6	1,65E-04	1,72E-04	2,82E-04	5,16E-05	3,43E-05	5,01E-04	4,57E-04	1,71E-05	1,47E-06	3,24E-07	8,98E-08		7,21E-07		2,52E-07	7,50E-07
11.1.7	2,05E-04	1,85E-04	2,58E-04	6,75E-05	2,02E-05	8,67E-04	7,50E-04	2,95E-05	7,76E-06	4,17E-07		1,31E-07		1,39E-07	2,06E-07	6,98E-07
11.1.8	1,96E-04	1,77E-04	2,00E-04	5,68E-05	2,00E-05	4,94E-04	4,07E-04	2,15E-05	7,87E-06	5,07E-07		3,40E-07		1,42E-07	2,38E-07	6,26E-07
11.1.9	2,08E-04	2,10E-04	2,15E-04	9,21E-05	2,55E-05	7,06E-04	6,95E-04	3,14E-05	1,03E-05	3,63E-07		4,23E-07	1,09E-07	1,05E-07	1,73E-07	3,25E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.1.1		9,13E-05	5,61E-06			3,29E-06	9,19E-07			2,48E-06					
11.1.2		5,24E-05	1,72E-05			1,05E-06	5,23E-07								
11.1.3		6,44E-06	1,16E-05			3,51E-06	7,84E-07								
11.1.4		7,48E-06	8,78E-06			1,13E-05	8,22E-07								
11.1.5		8,67E-06	5,17E-06			1,49E-05	6,35E-07								
11.1.6		8,37E-06	1,57E-06			7,98E-05	5,98E-07		8,58E-08	4,70E-06					
11.1.7		5,30E-06					1,85E-06			1,76E-07					
11.1.8		4,52E-06					1,20E-06			9,15E-07					
11.1.9		5,53E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.1.1		3,35E-05	1,72E-05			8,61E-06	1,72E-05		2,54E-05	2,49E-05		1,64E-05			
11.1.2		4,99E-05	3,30E-05			2,37E-05	2,21E-05		4,25E-05	3,77E-05		2,86E-05			
11.1.3		1,73E-05	1,63E-05			1,55E-05	1,49E-05		1,42E-05	1,54E-05		1,25E-05			
11.1.4	3,84E-06	4,69E-06	2,16E-06	6,05E-06	2,54E-06	2,74E-06	2,00E-06	1,73E-06	2,16E-06	2,37E-06	3,71E-06	3,98E-06	2,75E-06	3,04E-06	3,28E-06
11.1.5		1,64E-05	1,06E-05			8,61E-06	8,22E-06		1,11E-05	1,05E-05		1,78E-05			9,86E-06
11.1.6	9,72E-06	2,18E-05	5,31E-06	9,61E-06	4,67E-06	7,17E-06	4,48E-06	5,28E-07	5,31E-06	5,74E-06	9,00E-06	1,04E-05	6,90E-06	7,46E-06	6,65E-06
11.1.7	4,37E-06	1,31E-05	1,45E-06	2,80E-06	4,44E-06	4,62E-06	8,53E-07	1,10E-06	9,27E-07	1,55E-06	1,61E-06	1,34E-06	1,11E-06	9,88E-07	1,39E-06
11.1.8		6,76E-06					8,22E-07		6,98E-07	1,63E-06					
11.1.9	4,38E-06	7,78E-06	2,56E-06	3,24E-06	2,26E-06	2,39E-06	2,70E-06	1,77E-06	1,97E-06	1,99E-06	6,02E-07	1,94E-06	2,52E-06	1,98E-06	1,94E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.2

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.2.1	1,51E-03	7,94E-04	2,96E-03	4,99E-05	8,62E-05	6,22E-05	5,02E-05	1,82E-05	1,30E-05	3,35E-06		6,79E-08	8,65E-07		2,17E-07	1,32E-06
11.2.2	6,37E-04	3,96E-04	9,40E-04	1,94E-04	3,45E-04	2,45E-05	2,04E-05	1,31E-05	1,88E-06	2,73E-06		5,06E-07	7,25E-07	4,47E-07	5,90E-07	2,09E-06
11.2.3	1,43E-04	1,23E-04	1,30E-04	8,85E-05	2,37E-04	3,75E-05	7,09E-05	6,48E-06	5,28E-07	9,23E-07		5,44E-07	6,96E-07	4,21E-07	2,82E-07	
11.2.4	1,57E-04	1,41E-04	1,23E-04	7,40E-05	1,33E-04	6,97E-05	3,62E-04	1,94E-05	4,60E-06	2,25E-06		1,17E-06	2,61E-07	4,87E-07	1,12E-06	2,75E-07
11.2.5	1,48E-04	1,35E-04	1,44E-04	3,57E-05	2,28E-04	2,85E-04	7,72E-04	1,00E-05	1,47E-06	5,24E-07		5,65E-07	7,51E-07	3,68E-07	6,82E-07	1,75E-06
11.2.6	2,10E-04	1,96E-04	3,45E-04	6,50E-05	5,67E-05	5,99E-04	7,37E-04	1,79E-05	9,93E-07	2,47E-07	6,40E-07	7,19E-07	7,65E-07	7,48E-07	6,07E-07	2,13E-06
11.2.7	2,40E-04	2,24E-04	3,04E-04	7,56E-05	1,77E-05	9,54E-04	8,88E-04	2,60E-05	4,17E-06	2,48E-07	3,43E-08	1,94E-07		1,72E-07	2,56E-07	7,86E-07
11.2.8	1,62E-04	1,47E-04	1,72E-04	6,05E-05	1,59E-05	6,16E-04	5,09E-04	2,03E-05	3,89E-06	3,07E-07	9,78E-08	3,37E-07	7,20E-08	1,86E-07	2,45E-07	3,11E-07
11.2.9	1,96E-04	1,98E-04	2,01E-04	8,94E-05	2,29E-05	8,25E-04	7,11E-04	3,36E-05	6,51E-06	2,47E-07	6,55E-08	1,11E-06	1,57E-06	3,40E-07	2,82E-07	3,51E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.2.1		1,18E-04	5,41E-06			3,79E-06	8,83E-07			9,20E-07					
11.2.2		4,40E-05	1,65E-05			2,33E-06	5,89E-07								
11.2.3		5,71E-06	8,85E-06			1,96E-06	3,92E-07			6,43E-07					
11.2.4		6,40E-06	1,13E-05			1,60E-05	6,54E-07								
11.2.5		8,63E-06	5,33E-06			2,95E-05	3,92E-07								
11.2.6		1,08E-05	1,74E-06			1,11E-04	6,54E-07		8,17E-08	4,79E-07					
11.2.7		6,77E-06					2,67E-06			1,78E-07					
11.2.8		3,15E-06					7,85E-07								
11.2.9		4,99E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.2.1		5,16E-05	2,87E-05			1,43E-05	2,27E-05		3,79E-05	5,20E-05		2,43E-05			
11.2.2		1,18E-05	4,51E-06			3,09E-06	3,20E-06		5,64E-06	3,90E-06					
11.2.3		4,72E-06	3,74E-06			2,76E-06	2,81E-06		3,13E-06	4,30E-06					
11.2.4	3,54E-06	3,34E-06	1,73E-06	7,93E-06	3,41E-06	2,72E-06	1,52E-06	1,38E-06	1,55E-06	2,30E-06	3,90E-06	4,98E-06	2,33E-06	2,39E-06	2,41E-06
11.2.5	5,82E-06	8,03E-06	8,88E-07	3,77E-06	3,01E-06	2,78E-06	5,80E-07	3,85E-07	6,38E-07	7,57E-07	3,71E-06	3,41E-06	1,42E-06	1,49E-06	1,77E-06
11.2.6	8,32E-06	1,86E-05	3,24E-06	5,08E-06	3,00E-06	5,83E-06	2,41E-06	1,46E-07	3,04E-06	5,61E-06	9,18E-06	1,01E-05	5,42E-06	5,26E-06	4,43E-06
11.2.7	7,08E-06	2,52E-05		2,52E-06	4,33E-06	3,59E-06	7,19E-07	8,74E-07	7,16E-07	8,81E-07	1,46E-06	1,02E-06	1,02E-06	9,20E-07	1,10E-06
11.2.8		5,03E-06					<6,5E-07		1,62E-07	3,35E-07					
11.2.9	3,21E-06	9,07E-06		1,85E-06	9,60E-07		3,99E-07	2,64E-07	2,33E-07	3,05E-07			3,77E-07	2,23E-07	2,80E-07

Table B 4. (Continued)

FUEL SPECIMEN 11.3

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.3.1	1,40E-03	7,32E-04	3,29E-03	8,41E-05	1,43E-04	3,57E-05	2,90E-05	1,35E-05	3,42E-06	2,61E-06		1,88E-07	7,92E-08			7,44E-06
11.3.2	3,33E-04	2,64E-04	5,21E-04	1,71E-04	3,58E-04	1,06E-05	1,18E-05	1,20E-05	1,13E-06	2,69E-06	5,75E-07	2,24E-06	3,57E-07	1,55E-06	2,08E-06	4,81E-06
11.3.3	1,38E-04	1,20E-04	8,80E-05	7,13E-05	2,09E-04	4,20E-05	1,23E-04	7,37E-06	2,78E-07	8,15E-07	2,33E-07	1,62E-06	9,13E-07	7,63E-07	9,07E-07	2,41E-06
11.3.4	1,72E-04	1,52E-04	1,39E-04	7,48E-05	1,32E-04	6,15E-05	3,13E-04	2,75E-05	2,99E-06	1,27E-06		1,02E-06	4,97E-07	8,28E-07	1,08E-06	2,89E-06
11.3.5	1,87E-04	1,74E-04	2,01E-04	5,57E-05	8,07E-05	2,31E-04	8,39E-04	1,12E-05	1,69E-06	3,50E-07	1,99E-07	6,38E-07	7,61E-07	5,59E-07	9,03E-07	1,39E-06
11.3.6	5,46E-04	5,35E-04	7,40E-04	3,56E-04	1,56E-04	1,12E-03	1,25E-03	1,48E-04	5,86E-05	1,14E-05	1,29E-05	6,09E-05	5,08E-07	3,84E-05	4,97E-05	5,70E-05
11.3.7	3,23E-04	3,08E-04	3,77E-04	1,29E-04	5,73E-05	1,65E-03	1,67E-03	7,33E-05	1,89E-05	3,48E-06	2,19E-06	1,15E-05		7,33E-06	8,54E-06	1,05E-05
11.3.8	1,80E-04	1,65E-04	2,02E-04	7,17E-05	3,27E-05	8,19E-04	6,56E-04	2,28E-05	5,87E-06	1,93E-06	1,41E-06	5,33E-07		3,91E-06	4,46E-06	5,65E-06
11.3.9	1,86E-04	1,88E-04	1,89E-04	9,66E-05	3,07E-05	9,68E-04	7,63E-04	3,45E-05	6,36E-06	1,44E-06	6,39E-07	3,63E-06	3,42E-07	2,07E-06	2,24E-06	2,66E-06

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.3.1		1,14E-04	1,52E-05			1,68E-06	5,20E-07			7,56E-07					
11.3.2		2,18E-05	1,52E-05			1,79E-06	9,10E-07			2,03E-06					
11.3.3		4,15E-06	7,03E-06			4,46E-06	3,90E-07			1,01E-06					
11.3.4		6,42E-06	9,10E-06			1,11E-05	9,75E-07			8,62E-07					
11.3.5		1,10E-05	8,18E-06			3,02E-05	4,74E-07			5,23E-07					
11.3.6		2,12E-05	8,35E-06			1,37E-04	3,83E-06		3,87E-07	4,21E-06		1,60E-06			1,20E-05
11.3.7		8,93E-06					4,16E-06			2,07E-06					5,07E-06
11.3.8		4,65E-06					1,04E-06			9,74E-07					3,15E-06
11.3.9		4,52E-06													2,72E-06

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.3.1		4,20E-05	1,72E-05			7,22E-06	1,30E-05		1,84E-05	1,84E-05		1,46E-05			
11.3.2		1,05E-05	6,33E-06			5,28E-06	5,20E-06		5,85E-06	7,08E-06		5,58E-06			9,40E-06
11.3.3		4,28E-06	3,82E-06			5,10E-06	2,86E-06		3,93E-06	3,72E-06					
11.3.4	2,09E-06	2,25E-06	1,28E-06	5,97E-07	1,13E-06	1,48E-06	7,64E-07	6,32E-07	8,84E-07	1,40E-06	1,81E-06	2,06E-06	1,10E-06	1,11E-06	1,20E-06
11.3.5	4,42E-06	8,18E-06	9,15E-07	3,13E-06	9,15E-06	2,94E-06	6,75E-07	4,12E-07	6,74E-07	1,24E-06	1,90E-06	2,06E-06	1,17E-06	1,26E-06	1,20E-06
11.3.6		1,60E-05	3,24E-06			5,15E-06	4,00E-05		2,67E-06	7,25E-06		2,52E-05			1,31E-05
11.3.7	6,72E-06	2,08E-05	7,86E-07	4,59E-06	4,72E-06	4,04E-06	2,33E-07	2,56E-07	9,17E-08	1,37E-06	2,30E-06	4,11E-07	1,64E-06	1,57E-06	2,78E-06
11.3.8		4,33E-06					<6,5E-07			4,23E-07					9,64E-07
11.3.9	3,25E-06	8,34E-06		1,31E-06	6,09E-07		5,39E-08		5,18E-08	5,14E-07			6,72E-07	4,94E-07	1,17E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.4

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.4.1	2,39E-03	1,19E-03	4,88E-03	1,32E-04	2,02E-04	5,33E-05	4,26E-05	1,61E-05	1,26E-05	2,99E-06		8,13E-08	4,85E-07		2,55E-08	2,52E-06
11.4.2	3,49E-04	2,87E-04	4,92E-04	1,97E-04	3,27E-04	7,17E-06	1,22E-05	8,83E-06	7,93E-07	2,28E-06	7,16E-07	2,46E-06	8,64E-07	1,68E-06	2,15E-06	3,70E-06
11.4.3	1,69E-04	1,48E-04	1,19E-04	9,27E-05	1,94E-04	4,70E-05	1,40E-04	9,86E-06	6,04E-07	1,16E-06	4,97E-07	1,62E-06	4,72E-07	1,53E-06	1,89E-06	1,72E-06
11.4.4	2,11E-04	1,89E-04	1,43E-04	8,38E-05	1,68E-04	1,08E-04	5,25E-04	2,71E-05	2,00E-06	1,14E-06	2,30E-07	1,66E-06	5,40E-07	1,29E-06	2,35E-06	5,59E-07
11.4.5	1,96E-04	1,83E-04	1,79E-04	6,01E-05	1,01E-04	4,19E-04	1,10E-03	1,32E-05	2,39E-06	4,10E-07	2,21E-07	7,33E-07	7,76E-07	7,83E-07	1,07E-06	1,77E-06
11.4.6	2,62E-04	2,50E-04	3,24E-04	1,12E-04	2,98E-05	1,03E-03	1,29E-03	2,49E-05	2,19E-06	2,38E-07	5,08E-07	1,16E-06	7,44E-07	4,38E-07	1,16E-06	1,12E-06
11.4.7	3,05E-04	2,90E-04	3,24E-04	1,23E-04	3,40E-05	1,28E-03	1,27E-03	4,08E-05	5,92E-06	2,92E-07	6,76E-08	5,26E-07		3,44E-07	4,50E-07	8,41E-07
11.4.8	1,97E-04	1,83E-04	2,06E-04	8,53E-05	2,97E-05	7,36E-04	6,08E-04	2,76E-05	5,79E-06	2,31E-07	6,69E-08	6,10E-07	4,24E-07	2,86E-07	3,56E-07	3,91E-07
11.4.9	2,35E-04	2,37E-04	2,37E-04	1,19E-04	3,86E-05	9,71E-04	7,89E-04	4,29E-05	7,64E-06	2,25E-07	4,61E-08	1,50E-06	1,16E-06	3,66E-07	4,38E-07	4,17E-07

RELEASE FRACTIONS: MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.4.1		2,75E-04	2,48E-05			2,54E-06	1,22E-06		1,05E-06	1,08E-06					
11.4.2		2,33E-05	2,20E-05			1,88E-06	1,06E-06			1,95E-06					
11.4.3		4,90E-06	1,05E-05			5,72E-06	4,93E-07			1,30E-06					
11.4.4		6,80E-06	9,50E-06			1,20E-05	7,75E-07			9,66E-07					
11.4.5		9,15E-06	7,57E-06			3,98E-05	5,99E-07			5,67E-07					
11.4.6		1,01E-05	3,13E-06			1,75E-04	8,45E-07		5,46E-08	3,75E-07					
11.4.7		5,01E-06					2,96E-06			1,33E-07					
11.4.8		4,22E-06					1,10E-06			1,47E-07					
11.4.9		6,91E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.4.1		7,91E-05	3,25E-05			1,63E-05	2,82E-05		3,35E-05	3,32E-05		2,58E-05			
11.4.2		1,66E-05	1,27E-05			9,35E-06	1,02E-05		1,13E-05	1,11E-05		1,14E-05			1,43E-05
11.4.3		2,37E-06	1,62E-06			<1.4E-06	1,20E-06		1,28E-06	1,37E-06					
11.4.4	3,93E-06	4,49E-06	1,60E-06	3,21E-06	1,83E-06	2,78E-06	1,19E-06	1,16E-06	1,26E-06	1,25E-06	2,87E-06	2,84E-06	1,94E-06	2,16E-06	
11.4.5	4,74E-06	6,69E-06	1,26E-06	2,91E-06	3,19E-06	4,61E-06	9,02E-07	4,97E-07	7,87E-07	1,26E-06	2,73E-06	1,83E-06	1,54E-06	1,63E-06	1,31E-06
11.4.6	8,00E-06	1,63E-05	1,84E-06	4,10E-06	2,37E-06	3,28E-06	9,76E-07		9,58E-07	1,28E-06	2,61E-06	2,67E-06	2,00E-06	2,00E-06	1,65E-06
11.4.7	5,39E-06	1,23E-05	6,68E-07	1,84E-06	3,75E-06	3,97E-06	4,73E-07	3,71E-07	3,83E-07	4,63E-07	8,83E-07	6,37E-07	5,76E-07	5,17E-07	7,08E-07
11.4.8		9,08E-06					<7,0E-07		3,37E-07	4,67E-07					
11.4.9	4,04E-06	9,27E-06		1,88E-06	6,92E-07		3,54E-07	1,31E-07	2,04E-07	1,80E-07			3,88E-07	2,43E-07	2,97E-07

Table B 4. (Continued)

FUEL SPECIMEN 11.5

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.5.1	3,66E-03	1,62E-03	7,22E-03	1,97E-04	3,94E-04	4,25E-05	3,20E-05	1,28E-05	8,74E-06	2,69E-06		4,90E-08	5,54E-07		5,91E-09	4,04E-06
11.5.2	2,23E-04	2,25E-04	1,84E-04	2,26E-04	4,15E-04	6,01E-06	7,49E-06	7,27E-06	6,09E-07	3,93E-06	7,62E-07	2,63E-06	2,79E-07	1,93E-06	2,59E-06	4,42E-06
11.5.3	1,84E-04	1,66E-04	9,62E-05	9,10E-05	1,58E-04	2,26E-05	7,21E-05	3,88E-06	7,22E-08	8,99E-07	3,97E-07	1,82E-06	4,10E-07	1,28E-06	2,18E-06	1,47E-06
11.5.4	1,80E-04	1,67E-04	1,00E-04	8,82E-05	1,19E-04	6,01E-05	2,39E-04	4,96E-05	1,13E-06	7,27E-07	5,44E-07	5,13E-06	3,20E-07	1,77E-06	3,29E-06	5,31E-06
11.5.5	2,03E-04	1,90E-04	1,30E-04	7,70E-05	1,18E-04	2,01E-04	6,10E-04	2,35E-05	2,50E-06	4,44E-07	3,32E-07	1,27E-06	7,75E-07	8,79E-07	1,37E-06	2,19E-06
11.5.6	2,94E-04	2,82E-04	2,58E-04	1,57E-04	4,02E-05	8,77E-04	1,71E-03	3,44E-05	5,99E-06	3,43E-07	3,05E-07	8,19E-07	3,52E-07	5,56E-07	8,37E-07	6,71E-07
11.5.7	3,21E-04	3,07E-04	2,61E-04	1,39E-04	3,54E-05	1,89E-03	2,12E-03	4,00E-05	6,66E-06	3,40E-07	1,07E-07	7,20E-07		4,21E-07	5,50E-07	8,03E-07
11.5.8	2,17E-04	2,04E-04	1,97E-04	9,90E-05	3,22E-05	8,60E-04	6,19E-04	3,28E-05	6,82E-06	3,38E-07	9,81E-08	5,33E-07	5,05E-08	3,43E-07	3,93E-07	5,40E-07
11.5.9	2,63E-04	2,65E-04	2,43E-04	1,36E-04	4,40E-05	1,19E-03	8,14E-04	5,18E-05	9,26E-06	2,59E-07	5,78E-08	1,86E-06	1,56E-06	5,79E-07	5,44E-07	5,63E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.5.1		5,38E-04	3,29E-05			2,21E-06	1,80E-06		1,60E-06	1,22E-06					
11.5.2		1,03E-05	3,76E-05			2,44E-06	7,63E-07			2,18E-06					
11.5.3		4,32E-06	9,01E-06			2,44E-06	4,86E-07			1,06E-06					
11.5.4		4,22E-06	9,81E-06			1,09E-05	1,04E-06			1,21E-06					
11.5.5		1,01E-05	1,53E-05			3,00E-05	1,27E-06			9,76E-07					
11.5.6		6,72E-06	3,57E-06			1,85E-04	9,37E-07		6,20E-08	6,70E-07					1,37E-06
11.5.7		5,00E-06					2,25E-06			2,48E-07					
11.5.8		4,85E-06					1,51E-06			1,50E-07					
11.5.9		6,30E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.5.1		2,10E-04	1,59E-04			8,22E-05	1,30E-04		1,80E-04	1,57E-04		1,51E-04			
11.5.2		1,87E-05	1,63E-05			1,33E-05	1,35E-05		1,71E-05	1,53E-05		1,55E-05			2,33E-05
11.5.3		3,57E-06	3,03E-06			4,26E-06	2,19E-06		2,62E-06	2,48E-06					
11.5.4	2,84E-06	3,30E-06	8,27E-07	2,83E-06	9,96E-07	1,20E-06	5,29E-07	4,33E-07	4,23E-07	8,30E-07	2,65E-06	2,79E-06	1,42E-06	1,40E-06	1,81E-06
11.5.5	5,22E-06	5,48E-06	1,90E-06	5,01E-06	2,76E-06	3,73E-06	1,15E-06	8,94E-07	1,05E-06	1,29E-06	3,81E-06	3,69E-06	2,15E-06	2,25E-06	2,20E-06
11.5.6	9,32E-06	1,14E-05	2,89E-06	3,92E-06	3,04E-06	7,51E-06	1,78E-06	7,38E-07	1,10E-06	1,57E-06	2,94E-06	3,09E-06	2,00E-06	2,26E-06	2,07E-06
11.5.7	1,20E-05	2,19E-05	5,50E-06	6,35E-06	8,03E-06	7,58E-06	2,07E-06	2,22E-06	1,88E-06	2,28E-06	4,03E-06	1,82E-06	2,81E-06	2,43E-06	2,70E-06
11.5.8		8,35E-06					6,94E-07		5,23E-07	8,74E-07					1,40E-06
11.5.9	7,48E-06	1,78E-05	2,14E-06	4,96E-06	1,59E-06	1,12E-06	1,27E-06	7,97E-07	7,32E-07	9,66E-07		5,07E-07	1,37E-06	1,03E-06	1,34E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.6

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.6.1	3,71E-03	1,56E-03	6,98E-03	2,14E-05	9,02E-05	1,18E-04	1,09E-05	9,87E-07		2,01E-08		1,56E-07	5,07E-07		2,06E-08	2,47E-06
11.6.2	1,02E-04	8,58E-05	2,31E-04	1,59E-05	1,45E-04	8,01E-06	1,90E-06	1,73E-07	4,23E-08			4,03E-07	1,11E-06		1,47E-07	
11.6.3	5,31E-05	3,89E-05	5,79E-05	5,26E-05	1,69E-04	1,72E-05	1,30E-06	2,45E-07	3,62E-08			8,97E-08	5,89E-07	1,63E-08	1,13E-08	1,27E-07
11.6.4	2,31E-05	1,53E-05	2,03E-05	4,49E-05	9,92E-05	1,76E-05	1,02E-06	1,61E-07	6,83E-08			6,01E-08	4,10E-07	2,92E-08	1,28E-08	5,98E-07
11.6.5	2,39E-05	1,34E-05	1,37E-05	3,42E-05	8,52E-05	2,65E-05	2,11E-06	9,49E-08	5,32E-08	1,15E-08		1,38E-07	7,37E-07	1,88E-08	5,72E-08	5,11E-07
11.6.6	3,44E-05	2,52E-05	3,04E-05	3,85E-05	6,48E-05	1,00E-05	1,49E-06	9,52E-08	3,31E-08	3,94E-08	7,30E-09		4,33E-07	2,03E-08		
11.6.7	3,38E-05	2,19E-05	2,02E-05	2,46E-05	3,58E-05	6,37E-06	3,18E-06	9,09E-08	3,62E-07	7,21E-08		1,35E-07	1,06E-07	7,42E-08	8,61E-08	5,19E-07
11.6.8	3,90E-05	2,39E-05	2,97E-05	3,08E-05	2,76E-05	2,10E-05	9,22E-07	2,03E-07	3,77E-08	1,17E-08		9,57E-10	2,31E+09	9,15E-10	2,77E-09	1,26E-07
11.6.9	4,99E-05	5,03E-05	5,03E-05	5,31E-05	4,41E-05	5,46E-05	4,49E-06	2,07E-06	1,59E-07	1,87E-08	1,56E-07	1,36E-06	7,00E-07	4,80E-07	3,72E-07	6,60E-07

RELEASE FRACTIONS: MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.6.1		2,77E-04	3,23E-06			<1.1E-06	2,06E-07			2,77E-07					
11.6.2		1,21E-05	2,76E-06			7,61E-07	<6.8E-08								
11.6.3		3,03E-06	1,41E-05			<1.1E-06	5,48E-08			4,72E-07					
11.6.4		1,03E-06	7,22E-06			1,23E-06	4,11E-08								
11.6.5		1,01E-06	1,36E-05			<2.8E-06	3,43E-08								
11.6.6		2,11E-06	1,70E-05			2,13E-05	6,85E-08		1,69E-08	5,88E-08		2,47E-07			
11.6.7		8,20E-07					<5,5E-08			1,15E-07					
11.6.8		9,16E-07													
11.6.9															

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.6.1															
11.6.2		2,33E-05	1,34E-05			1,09E-05	8,70E-06		1,92E-05	1,61E-05		1,17E-05			
11.6.3		1,32E-05	1,44E-05			9,36E-06	8,77E-06		1,35E-05	1,00E-05		1,10E-05			1,28E-05
11.6.4	2,82E-06	3,05E-06	3,08E-06	1,72E-05	2,81E-06	2,85E-06	1,83E-06	2,20E-06	2,53E-06	2,36E-06	3,35E-06	4,35E-06	2,48E-06	2,58E-06	2,79E-06
11.6.5	2,69E-06	1,91E-06	1,81E-06	1,03E-05	1,82E-06	8,20E-07	9,39E-07	5,43E-07	1,17E-06	1,12E-06	2,35E-06	2,53E-06	1,39E-06	1,50E-06	1,27E-06
11.6.6	2,32E-06	2,06E-06	6,33E-07	1,26E-05	2,48E-06	7,27E-07	1,19E-07	1,42E-07	1,26E-07	1,66E-07	8,62E-07	1,46E-06	1,77E-07	2,38E-07	1,81E-07
11.6.7	8,30E-07	1,01E-06		2,87E-06	6,90E-07	8,83E-08	2,27E-07	3,69E-07	2,84E-07	2,99E-07	3,78E-06	1,85E-06	8,68E-07	5,51E-07	1,15E-07
11.6.8		8,63E-07					<6,8E-07								
11.6.9	1,49E-06	1,57E-06		1,82E-06	7,48E-07	6,52E-07	8,11E-07	6,74E-07	7,14E-07	7,64E-07		1,72E-06	1,10E-06	7,71E-07	1,16E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.7

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.7.1	3,61E-03	1,33E-03	6,10E-03	1,82E-05	1,51E-04	9,21E-06	2,27E-05	9,62E-06	1,28E-05	4,84E-06		1,68E-07	6,11E-09			1,27E-05
11.7.2	1,49E-04	1,04E-04	2,42E-04	1,21E-05	7,39E-05	2,35E-05	2,41E-05	2,26E-06	2,41E-05	8,77E-06	1,02E-07	4,16E-07	7,80E-07		5,82E-08	
11.7.3	2,11E-04	1,97E-04	1,42E-04	2,94E-04	2,92E-04	3,06E-05	2,09E-05	1,99E-05	7,81E-06	3,28E-06	2,21E-07	1,60E-06	3,11E-07	8,60E-07	1,12E-06	1,59E-06
11.7.4	1,74E-04	1,73E-04	1,31E-04	1,09E-04	1,51E-04	2,65E-05	4,85E-05	1,08E-04	9,23E-05	8,51E-05	4,26E-05	1,90E-05	1,72E-05	1,80E-05	2,09E-05	1,38E-05
11.7.5	6,32E-05	6,21E-05	3,00E-05	2,28E-06	5,73E-06	1,55E-05	1,81E-05	2,45E-08	2,28E-05	4,30E-06	1,14E-07	4,30E-07	7,88E-07	3,33E-07	4,27E-07	8,82E-07
11.7.6	1,69E-04	1,67E-04	9,00E-05	1,47E-04	6,04E-05	1,06E-05	9,80E-05	4,89E-09	1,32E-05	2,62E-06	2,61E-06	1,31E-05	8,99E-07	5,21E-06	6,60E-06	3,63E-06
11.7.7	6,08E-04	6,05E-04	6,88E-04	6,60E-05	2,69E-07	8,01E-03	1,36E-06	9,24E-05	1,14E-06	1,61E-07	2,04E-07	2,48E-07	2,63E-07	1,84E-07	2,38E-07	7,51E-07
11.7.8	1,44E-04	1,36E-04	2,81E-04	8,96E-05	4,02E-06	6,59E-04	2,32E-07	8,44E-06	3,43E-07	9,53E-09		2,43E-07	1,06E-07	7,47E-08	1,06E-07	1,05E-07
11.7.9	3,40E-05	3,42E-05	7,96E-05	8,03E-05	7,44E-06	4,40E-05	1,51E-06	3,85E-05	5,76E-07	7,67E-08	2,22E-07	7,36E-07	5,40E-07	5,14E-07	5,22E-07	7,23E-07

RELEASE FRACTIONS: MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.7.1		1,35E-03	4,74E-05			3,43E-06	2,50E-06		1,66E-06	1,13E-06					
11.7.2		1,42E-04	1,31E-04			5,88E-07	6,40E-07		1,41E-06	3,48E-06					
11.7.3		5,84E-06	4,25E-05			<1.0E-06	1,59E-06			6,66E-07					
11.7.4		1,58E-05	6,35E-05			1,00E-05	2,26E-05		2,07E-05	1,97E-04		9,12E-04			2,73E-04
11.7.5		2,38E-05	1,29E-04			<2.5E-06	3,49E-08		8,29E-07	3,82E-06					
11.7.6		5,63E-06	2,94E-06			2,57E-05	<6.1E-08		2,23E-07	4,97E-06		1,72E-06			1,02E-05
11.7.7		2,24E-05					1,27E-05		3,86E-07	1,71E-06		3,91E-06			3,68E-06
11.7.8		7,33E-06													
11.7.9															

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.7.1		4,20E-04	2,36E-05			8,82E-06	1,65E-05		3,09E-05	2,21E-05					
11.7.2		2,13E-05	4,01E-06			1,81E-06	2,50E-06		3,22E-06	4,36E-06					
11.7.3		3,05E-06	2,96E-06			9,70E-07	1,31E-06		1,72E-06	1,54E-06					
11.7.4	5,94E-06	3,87E-06	2,90E-06	3,99E-06	2,03E-06	1,95E-06	2,29E-06	1,75E-06	2,02E-06	2,30E-06	4,09E-06	4,18E-06	2,90E-06	3,13E-06	3,11E-06
11.7.5	3,72E-05	3,31E-05	1,21E-05	3,38E-05	1,50E-06	9,66E-07	2,35E-06	1,07E-06	1,21E-06	6,66E-06	1,39E-05	4,18E-06	7,61E-06	9,83E-06	1,06E-05
11.7.6	9,47E-05	6,35E-05	1,35E-05	3,88E-05	5,81E-07	5,84E-07	8,43E-07	4,91E-08	1,25E-07	3,75E-06	9,21E-06	3,93E-06	4,46E-06	6,52E-06	8,06E-06
11.7.7	1,10E-05	1,47E-05	1,40E-05	6,83E-06	1,44E-05		1,73E-05	6,93E-07	2,75E-07	5,47E-07	3,62E-06	2,69E-06	1,99E-06	2,52E-05	2,83E-06
11.7.8		3,44E-06					6,10E-07								
11.7.9	7,44E-07	2,51E-06	5,70E-06	2,03E-05	1,09E-07	7,63E-08	2,45E-05	8,69E-07	2,48E-07	3,03E-07		1,72E-06	8,48E-07	7,96E-07	1,11E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.8

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.8.1	4,53E-03	1,70E-03	7,72E-03	1,59E-04	5,07E-04	9,44E-05	4,36E-05	1,45E-05	3,57E-06	1,60E-06	8,28E-08	4,01E-07	7,16E-07	1,07E-07	1,71E-07	1,50E-05
11.8.2	6,06E-04	3,55E-04	6,48E-04	2,83E-04	5,43E-04	7,84E-06	8,34E-06	7,61E-06	8,42E-07	2,63E-06	8,03E-07	3,59E-06	1,19E-06	1,67E-06	2,21E-06	2,29E-06
11.8.3	2,11E-04	1,91E-04	1,20E-04	9,88E-05	2,60E-04	2,74E-05	6,83E-05	4,49E-06	1,71E-07	8,22E-07	2,74E-07	1,99E-06	4,16E-07	1,52E-06	2,23E-06	2,06E-06
11.8.4	2,01E-04	1,81E-04	1,24E-04	8,81E-05	1,31E-04	7,98E-05	2,46E-04	4,56E-05	9,82E-07	7,75E-07	2,22E-07	2,16E-06	2,77E-07	1,48E-06	2,56E-06	1,88E-06
11.8.5	2,25E-04	2,10E-04	1,58E-04	8,35E-05	1,04E-04	3,15E-04	1,18E-03	2,35E-05	3,47E-06	4,11E-07	3,56E-07	1,38E-06	6,94E-07	1,16E-06	1,67E-06	2,55E-06
11.8.6	2,64E-04	2,47E-04	2,81E-04	1,36E-04	5,00E-05	1,12E-03	1,54E-03	4,42E-05	5,50E-06	3,48E-07	3,58E-07	1,29E-06	3,41E-07	7,47E-07	1,19E-06	1,65E-06
11.8.7	3,13E-04	2,97E-04	3,00E-04	1,40E-04	4,97E-05	1,33E-03	1,27E-03	6,11E-05	1,06E-05	4,03E-07	1,14E-07	9,59E-07		6,02E-07	7,66E-07	1,22E-06
11.8.8	2,15E-04	2,04E-04	2,09E-04	9,54E-05	3,80E-05	6,56E-04	4,79E-04	3,75E-05	9,02E-06	3,64E-07	1,44E-07	7,05E-07		3,93E-07	5,00E-07	6,94E-07
11.8.9	2,97E-04	2,99E-04	2,97E-04	1,66E-04	5,18E-05	7,83E-04	6,59E-04	5,48E-05	1,25E-05	3,57E-07	1,44E-07	5,57E-07		3,59E-07	4,31E-07	6,55E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.8.1		2,11E-04	1,95E-05			4,47E-06	9,92E-07		1,32E-06	2,26E-06					
11.8.2		3,38E-05	3,62E-05			1,23E-06	5,38E-07			1,59E-06					
11.8.3		4,60E-06	1,37E-05			1,89E-06	4,14E-07			5,88E-07					
11.8.4		5,33E-06	1,02E-05			8,68E-06	1,49E-06			1,98E-06					
11.8.5		1,17E-05	1,36E-05			6,06E-05	1,32E-06			8,26E-07					
11.8.6		8,68E-06	3,92E-06			1,98E-04	1,57E-06		4,11E-08	3,08E-07					7,87E-07
11.8.7		5,72E-06					2,55E-06			1,84E-07					
11.8.8		4,30E-06					1,46E-06			7,35E-08					
11.8.9		7,19E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.8.1		7,48E-05	1,82E-05			9,20E-06	1,60E-05		2,20E-05	2,22E-05					
11.8.2		2,04E-05	6,80E-06			3,30E-06	3,97E-06		6,50E-06	5,55E-06		4,39E-06			7,41E-06
11.8.3		4,46E-06	3,17E-06			1,94E-06	1,86E-06		2,39E-06	2,76E-06					
11.8.4	2,25E-06	2,39E-06	1,49E-06	1,83E-06	1,10E-06	1,45E-06	1,08E-06	8,58E-07	8,81E-07	1,08E-06	1,57E-06	1,61E-06	1,08E-06	1,23E-06	1,36E-06
11.8.5	4,58E-06	6,22E-06	1,15E-06	2,24E-06	1,37E-05	4,46E-06	6,50E-07	2,84E-07	5,45E-07	8,07E-07	1,80E-06	1,53E-06	1,07E-06	1,24E-06	1,22E-06
11.8.6	7,01E-06	1,28E-05	1,74E-06	3,81E-06	3,44E-06	5,77E-06	1,13E-06	6,79E-07	9,07E-07	9,87E-07	2,11E-06	1,79E-06	1,35E-06	1,55E-06	1,31E-06
11.8.7	6,31E-06	1,03E-05	3,76E-06	6,04E-06	4,67E-06	4,32E-06	9,64E-07	9,32E-07	6,50E-07	8,66E-07	2,08E-06	1,86E-06	1,07E-06	1,03E-06	1,17E-06
11.8.8		1,40E-05					<8,3E-07		2,02E-07	4,71E-07					
11.8.9	5,02E-06	1,09E-05	9,85E-07	2,75E-06	2,33E-06	1,40E-06	4,80E-07	2,31E-07	2,02E-07	2,71E-07		5,89E-07	6,50E-07	2,39E-07	2,46E-07

Table B 4. (Continued)

FUEL SPECIMEN 11.9

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.9.1	4,05E-03	1,46E-03	6,87E-03	1,82E-05	6,17E-05	5,49E-05	7,75E-06	1,34E-06		5,29E-09		8,14E-08	5,33E-07	1,91E-08	3,19E-08	1,27E-06
11.9.2	3,10E-04	1,63E-04	7,39E-04	9,73E-06	1,03E-04	5,20E-06	1,53E-06	3,07E-07	1,87E-07	3,59E-09		7,99E-08	5,43E-07	7,34E-08	6,27E-08	1,38E-07
11.9.3	6,28E-05	4,88E-05	1,06E-04	1,26E-05	1,00E-04	9,96E-06	1,74E-06	1,56E-07	3,03E-08			4,73E-07	9,23E-07	7,54E-08	4,62E-08	
11.9.4	4,19E-05	3,18E-05	4,24E-05	3,61E-05	1,29E-04	1,72E-05	6,47E-07	1,31E-07					7,63E-07	8,63E-08	4,85E-08	9,20E-07
11.9.5	2,87E-05	2,04E-05	2,39E-05	6,97E-05	1,43E-04	2,18E-05	6,89E-07	1,65E-07	3,94E-08			8,18E-08	4,77E-07		1,62E-08	8,94E-07
11.9.6	2,94E-05	1,82E-05	3,54E-05	5,13E-05	7,16E-05	1,39E-05	1,61E-06	1,93E-07	6,39E-08	1,46E-08	3,09E-08	2,38E-07	6,57E-07	8,93E-08	1,03E-07	5,60E-07
11.9.7	3,23E-05	2,18E-05	2,17E-05	2,49E-05	4,17E-05	8,42E-06	1,41E-06	3,14E-07	3,46E-07	6,11E-08	2,99E-08	7,59E-08	5,81E-08	5,41E-08	7,56E-08	4,75E-07
11.9.8	4,41E-05	3,23E-05	3,78E-05	4,19E-05	4,23E-05	3,75E-05	7,59E-07	3,96E-07	6,44E-08	9,87E-09		1,10E-07	5,38E-08	3,72E-08	3,95E-08	2,94E-07
11.9.9	8,26E-05	8,32E-05	7,16E-05	7,94E-05	5,30E-05	1,61E-04	5,16E-06	1,52E-05	4,79E-07	3,75E-08	3,75E-07	1,72E-06	1,22E-06	8,53E-07	6,18E-07	8,01E-07

RELEASE FRACTIONS: MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.9.1		3,22E-04	3,68E-06			1,25E-06	3,39E-07			1,81E-07					
11.9.2		3,56E-05	1,59E-06			6,96E-07	6,77E-08								
11.9.3		6,02E-06	4,29E-06			<1.0E-06	<2.7E-08								
11.9.4		4,36E-06	6,77E-06			5,82E-06	1,49E-06		1,69E-06	2,27E-06					
11.9.5		1,56E-06	1,98E-05			<2.6E-06	2,71E-08								
11.9.6		1,71E-06	2,43E-05			2,08E-07	6,77E-08		2,41E-08	1,44E-07					
11.9.7		8,42E-07					1,63E-07			2,05E-07					
11.9.8		1,22E-06													
11.9.9															

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.9.1		1,20E-04	7,61E-05			3,63E-05	5,83E-05		8,01E-05	8,03E-05		6,82E-05			
11.9.2		1,91E-05	8,48E-06			8,20E-06	4,81E-06		1,28E-05	8,51E-06		7,14E-06			
11.9.3		1,48E-05	1,47E-05			1,15E-05	1,08E-05		1,17E-05	1,25E-05		1,03E-05			1,39E-05
11.9.4		3,55E-05	3,38E-05			2,46E-06	2,68E-05		3,79E-05	4,48E-05		1,13E-04			3,67E-05
11.9.5	5,17E-06	3,90E-06	4,42E-06	2,86E-05	2,82E-06	2,02E-06	2,31E-06	2,38E-06	2,76E-06	3,30E-06	3,87E-06	4,63E-06	3,03E-06	3,36E-06	2,76E-06
11.9.6	7,73E-07	2,36E-06	4,66E-07	6,02E-06	1,37E-06	7,79E-07	1,53E-07	5,34E-07	8,18E-08	1,42E-07	7,04E-07	1,03E-06	1,86E-07	2,70E-07	1,92E-06
11.9.7	4,88E-07	1,52E-06	1,06E-06	6,08E-06	8,67E-07		5,97E-08	8,88E-08	1,19E-07	1,48E-07	3,49E-06	1,70E-06	6,52E-07	4,04E-07	
11.9.8		1,76E-06					<6,8E-07								
11.9.9	1,89E-06	2,44E-06	2,22E-06	4,11E-06	8,39E-07	5,92E-07	1,02E-06	8,42E-07	9,86E-07	1,76E-06	2,01E-07	2,82E-06	2,11E-06	1,66E-06	1,87E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.10

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.10.1	4,30E-03	1,59E-03	6,54E-03	6,82E-05	2,26E-04	9,52E-05	1,02E-04	1,83E-05	1,30E-05	2,92E-06		9,52E-07	9,06E-07	1,24E-07	1,77E-07	1,35E-05
11.10.2	1,16E-03	4,96E-04	1,74E-03	3,03E-04	4,20E-04	6,87E-06	6,75E-06	6,04E-06	1,55E-06	2,07E-06	1,05E-06	3,01E-06	3,21E-07	1,65E-06	2,47E-06	4,48E-06
11.10.3	1,77E-04	1,60E-04	1,46E-04	1,09E-04	2,03E-04	1,76E-05	2,64E-05	7,96E-06	1,24E-06	1,56E-06	7,94E-07	3,37E-06	5,39E-07	2,70E-06	3,13E-06	3,53E-06
11.10.4	1,99E-04	1,84E-04	1,26E-04	9,69E-05	1,70E-04	4,05E-05	9,11E-05	2,07E-05	1,34E-06	1,31E-06	6,49E-07	3,91E-06	4,96E-07	2,53E-06	2,91E-06	2,22E-06
11.10.5	1,98E-04	1,89E-04	1,53E-04	7,34E-05	6,06E-05	1,62E-04	3,94E-04	1,27E-05	1,78E-06	5,68E-07	6,46E-07	2,07E-06	6,43E-07	1,57E-06	2,23E-06	2,50E-06
11.10.6	3,00E-04	2,85E-04	3,02E-04	1,72E-04	6,23E-05	8,89E-04	1,61E-03	2,57E-05	1,04E-05	4,00E-07	5,19E-07	1,67E-06	4,73E-07	1,18E-06	1,71E-06	1,83E-06
11.10.7	2,98E-04	2,84E-04	2,76E-04	1,00E-04	4,11E-05	1,12E-03	1,31E-03	3,31E-05	8,25E-06	4,93E-07	1,10E-07	1,23E-07		8,03E-07	9,83E-07	1,35E-06
11.10.8	2,22E-04	2,10E-04	2,16E-04	8,29E-05	3,35E-05	5,09E-04	4,97E-04	2,33E-05	7,33E-06	3,85E-07	1,23E-07	5,50E-07		3,38E-07	4,32E-07	5,98E-07
11.10.9	2,99E-04	3,01E-04	2,95E-04	1,35E-04	4,54E-05	6,81E-04	6,48E-04	3,76E-05	1,12E-05	3,39E-07	8,85E-08	4,17E-07		2,90E-07	3,21E-07	5,31E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.10.1		5,46E-04	1,35E-05			1,70E-05	2,87E-06		2,36E-06	2,40E-06					
11.10.2		1,27E-04	3,26E-05			2,35E-06	2,46E-06		2,78E-06	5,81E-06					
11.10.3		6,07E-06	1,72E-05			1,88E-06	8,19E-07			8,82E-07					
11.10.4		5,69E-06	1,24E-05			2,59E-06	5,46E-07			1,17E-07					
11.10.5		7,67E-06	9,45E-06			1,35E-05	7,16E-07			1,31E-06					
11.10.6		9,96E-06	5,12E-06			1,74E-04	7,50E-07		2,39E-08	4,47E-07					1,06E-06
11.10.7		5,32E-06					1,66E-06			3,04E-07					
11.10.8		4,64E-06					1,58E-06			1,28E-07					
11.10.9		7,19E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.10.1		6,44E-05	3,00E-05			1,24E-05	2,21E-05		3,83E-05	2,89E-05		2,05E-05			2,76E-05
11.10.2		3,17E-05	2,06E-05			9,15E-06	1,47E-05		1,93E-05	1,95E-05		1,71E-05			2,19E-05
11.10.3		7,15E-06	7,09E-06			<1.0E-06	8,87E-07		6,18E-06	6,90E-06		4,91E-06			7,73E-06
11.10.4	2,07E-06	2,41E-06	7,89E-07	1,49E-06	4,25E-07	9,35E-07	2,45E-07	1,48E-07	1,31E-07	6,17E-07	1,16E-06	9,87E-07	6,48E-07	6,91E-07	1,08E-06
11.10.5	5,19E-06	7,27E-06	1,04E-06	3,03E-06	1,08E-05	1,91E-06	5,09E-07	1,16E-07	4,83E-07	9,41E-07	1,92E-06	1,51E-06	1,28E-06	1,39E-06	1,66E-06
11.10.6	6,62E-06	1,48E-05	1,29E-06	4,38E-06	4,35E-06	5,04E-06	4,17E-07	2,60E-07	2,92E-07	7,88E-07	1,37E-06	1,15E-06	9,44E-07	1,08E-06	1,02E-06
11.10.7	5,10E-06	9,62E-06	1,57E-06	6,64E-06	3,69E-06	4,38E-06	5,58E-07	5,92E-07	3,61E-07	6,78E-07	1,75E-06	1,60E-06	9,23E-07	7,68E-07	8,96E-07
11.10.8		1,08E-05					1,13E-06		4,75E-07	1,33E-06					1,60E-06
11.10.9	5,61E-06	1,06E-05	1,28E-06	2,46E-06	2,88E-06	2,36E-06	1,02E-06	5,22E-07	4,13E-07	6,67E-07			8,70E-07	5,89E-07	6,01E-07

Table B 4. (Continued)

FUEL SPECIMEN 11.11

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.11.1	2,42E-03	8,55E-04	5,08E-03	7,69E-03	2,31E-04	5,07E-05	7,86E-05	1,69E-05	7,45E-06	2,22E-06		2,74E-07	5,17E-07	5,47E-08	4,28E-08	1,52E-06
11.11.2	1,24E-03	5,49E-04	1,46E-03	2,60E-04	3,98E-04	7,02E-06	7,27E-06	5,33E-06	4,89E-07	1,78E-06	2,75E-06	6,82E-06	7,87E-07	5,66E-06	7,06E-06	1,21E-05
11.11.3	1,68E-04	1,52E-04	1,08E-04	1,02E-04	1,78E-04	2,33E-05	4,73E-05	1,77E-05	4,95E-07	2,00E-06	5,13E-07	2,95E-06	2,68E-07	2,73E-06	3,03E-06	2,99E-06
11.11.4	2,02E-04	1,79E-04	1,48E-04	8,19E-05	2,04E-04	5,86E-05	1,40E-04	3,30E-05	1,92E-06	1,35E-06	4,00E-07	1,87E-06	5,11E-07	1,27E-06	2,01E-06	3,43E-06
11.11.5	1,78E-04	1,69E-04	1,47E-04	5,70E-05	9,23E-05	2,34E-04	7,18E-04	1,85E-05	1,54E-06	8,04E-07	4,08E-07	1,43E-06	6,42E-07	1,15E-06	1,68E-06	2,50E-06
11.11.6	2,39E-04	2,27E-04	2,61E-04	1,17E-04	3,76E-05	8,56E-04	1,28E-03	3,01E-05	6,90E-06	4,34E-07	2,75E-07	9,06E-07	2,30E-07	5,41E-07	7,46E-07	1,13E-06
11.11.7	3,00E-04	2,85E-04	3,11E-04	1,09E-04	3,59E-05	1,16E-03	1,14E-03	3,80E-05	8,60E-06	6,50E-07	1,08E-07	6,85E-07		5,07E-07	6,14E-07	1,03E-06
11.11.8	2,06E-04	1,93E-04	2,33E-04	8,54E-05	3,03E-05	4,88E-04	4,53E-04	2,67E-05	6,99E-06	4,49E-07	9,94E-08	4,80E-07	1,30E-08	2,81E-07	3,48E-07	4,51E-07
11.11.9	2,69E-04	2,71E-04	3,06E-04	1,32E-04	3,78E-05	6,65E-04	5,81E-04	3,87E-05	8,89E-06	3,89E-07	7,41E-08	3,62E-07	1,72E-08	1,95E-07	2,01E-07	3,08E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.11.1		5,72E-04	1,47E-05			3,05E-05	3,88E-06		4,43E-06	4,68E-06					
11.11.2		9,25E-05	3,26E-05			9,87E-07	7,48E-07		1,83E-06	7,30E-06					
11.11.3		6,61E-06	1,36E-05			2,09E-06	2,31E-06		1,01E-06	7,77E-07					
11.11.4		6,54E-06	1,03E-05			5,98E-06	1,12E-06			1,04E-06					
11.11.5		7,63E-06	8,72E-06			2,22E-05	8,50E-07			1,12E-06					
11.11.6		6,65E-06	2,72E-06			1,29E-04	8,84E-07		5,06E-08	3,10E-07					7,95E-07
11.11.7		6,60E-06					1,80E-06			2,99E-07					5,55E-07
11.11.8		5,07E-06					9,52E-07			1,87E-07					
11.11.9		8,46E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.11.1		9,32E-05	4,92E-05			2,59E-05	3,81E-05		5,60E-05	5,87E-05		5,08E-05			5,43E-05
11.11.2		2,49E-05	1,41E-05			1,02E-05	9,86E-06		1,19E-05	1,16E-05		1,37E-05			1,44E-05
11.11.3		1,94E-05	1,99E-05			5,62E-06	1,47E-05		1,70E-05	1,84E-05		1,80E-05			1,84E-05
11.11.4	2,45E-06	2,35E-06	8,07E-07	4,47E-06	1,53E-06	8,88E-07	5,70E-07	5,36E-07	4,69E-07	6,39E-07	2,05E-06	2,77E-06	9,77E-07	9,68E-07	1,18E-06
11.11.5	3,62E-06	4,46E-06	1,07E-06	2,29E-06	1,07E-05	3,10E-06	7,37E-07	6,01E-07	6,75E-07	8,99E-07	1,64E-06	1,71E-06	1,21E-06	1,31E-06	1,15E-06
11.11.6	7,13E-06	1,37E-05	1,22E-06	7,38E-06	2,91E-06	4,69E-06	8,20E-07	2,80E-07	4,02E-07	6,39E-07	1,52E-06	1,10E-06	1,01E-06	1,03E-06	1,10E-06
11.11.7	2,74E-06	5,16E-06	1,98E-06	1,53E-06	3,93E-06	3,29E-06	4,56E-07	4,80E-07	5,11E-07	6,39E-07	1,20E-06	9,84E-07	8,10E-07	7,45E-07	6,80E-07
11.11.8		7,60E-06					<6,8E-07		4,76E-07	4,85E-07					9,05E-07
11.11.9	5,24E-06	1,16E-05	1,04E-06	2,17E-06	2,20E-06	2,16E-06	9,09E-07	4,65E-07	4,79E-07	6,14E-07	5,89E-07	2,39E-07	7,49E-07	6,63E-07	6,02E-07

Table B 4. (Continued)

FUEL SPECIMEN 11.12

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.12.1	2,52E-03	8,84E-04	4,19E-03	4,97E-05	1,74E-04	9,76E-05	7,76E-05	2,56E-05	1,48E-05	3,02E-06		6,08E-08	1,60E-07	2,83E-08	6,08E-08	4,83E-06
11.12.2	2,24E-03	8,67E-04	3,09E-03	3,20E-04	5,24E-04	1,39E-05	1,11E-05	8,56E-06	7,02E-07	3,22E-06	4,29E-07	2,48E-06	3,48E-07	2,17E-06	2,48E-06	6,37E-06
11.12.3	1,76E-04	1,60E-04	1,28E-04	8,41E-05	1,93E-04	1,71E-05	4,20E-05	5,78E-06	3,89E-07	9,31E-07	3,47E-07	1,95E-06	7,59E-07	1,78E-06	1,95E-06	1,89E-06
11.12.4	1,73E-04	1,51E-04	1,43E-04	6,88E-05	1,79E-04	5,89E-05	1,30E-04	2,84E-05	8,89E-07	1,26E-06	4,58E-07	2,16E-06	3,89E-07	1,74E-06	2,16E-06	2,33E-06
11.12.5	1,92E-04	1,80E-04	1,93E-04	7,03E-05	9,73E-05	1,61E-04	3,77E-04	1,25E-05	1,58E-06	6,38E-07	4,55E-07	2,07E-06	7,23E-07	1,51E-06	2,07E-06	2,70E-06
11.12.6	2,43E-04	2,33E-04	3,00E-04	1,36E-04	5,70E-05	6,83E-04	1,29E-03	2,49E-05	7,00E-06	4,80E-07	4,05E-07	1,38E-06	7,73E-07	9,48E-07	1,38E-06	
11.12.7	2,80E-04	2,68E-04	4,19E-04	1,23E-04	4,42E-05	8,75E-04	1,09E-03	3,28E-05	7,24E-06	5,82E-07	1,66E-07	7,12E-07		5,72E-07	7,12E-07	9,43E-07
11.12.8	2,00E-04	1,87E-04	2,82E-04	8,79E-05	3,23E-05	3,60E-04	4,23E-04	2,47E-05	6,78E-06	4,70E-07	9,24E-08	2,93E-07		2,69E-07	2,93E-07	5,04E-07
11.12.9	2,51E-04	2,53E-04	2,90E-04	1,36E-04	4,16E-05	4,78E-04	5,37E-04	3,61E-05	9,38E-06	4,03E-07	1,09E-07	3,47E-07		3,25E-07	3,47E-07	4,96E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.12.1		3,65E-04	1,00E-05			2,64E-05	8,89E-06		1,06E-05	9,58E-06					
11.12.2		1,62E-04	3,36E-05			1,21E-06	9,02E-07		9,06E-07	1,41E-06					
11.12.3		6,40E-06	1,33E-05			1,71E-06	4,34E-07			1,13E-06					
11.12.4		6,54E-06	9,61E-06			5,26E-06	1,00E-06			1,03E-06					
11.12.5		9,95E-06	1,06E-05			9,80E-06	5,35E-07			9,08E-07					
11.12.6		8,10E-06	3,60E-06			1,65E-04	9,36E-07		1,19E-07	6,17E-07		3,18E-07			9,86E-07
11.12.7		7,18E-06					1,28E-06			1,80E-07					5,17E-07
11.12.8		5,68E-06					1,18E-06			2,76E-07					7,63E-07
11.12.9		8,88E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.12.1		1,40E-04	1,06E-04			5,34E-05	8,52E-05		1,25E-04	1,35E-04		1,02E-04			1,14E-04
11.12.2		4,09E-05	2,19E-05			1,41E-05	1,83E-05		2,37E-05	2,38E-05		2,15E-05			2,12E-05
11.12.3		2,31E-06	1,79E-06			1,02E-06	9,36E-07		2,02E-06	1,71E-06					
11.12.4		2,45E-06	9,41E-07			2,48E-06	6,35E-07		6,46E-07	1,09E-06					
11.12.5	5,23E-06	6,94E-06	1,61E-06	3,63E-06	2,24E-06	1,87E-06	1,04E-06	8,87E-07	1,23E-06	1,72E-06	2,79E-06	2,35E-06	1,96E-06	2,12E-06	1,91E-06
11.12.6	5,27E-06	8,25E-06	1,37E-06	3,46E-06	3,79E-06	4,77E-06	9,11E-07	5,87E-07	7,49E-07	1,01E-06	1,85E-06	1,65E-06	1,28E-06	1,44E-06	1,09E-06
11.12.7	4,64E-06	1,12E-05	1,45E-06	1,96E-06	2,54E-06	3,19E-06	3,32E-07	3,41E-07	2,21E-07	4,66E-07	1,50E-06	1,50E-06	6,39E-07	5,67E-07	7,26E-07
11.12.8		1,03E-05					8,02E-07		5,86E-07	9,68E-07					1,15E-06
11.12.9	5,60E-06	1,28E-05	1,71E-06	3,12E-06	1,89E-06	1,75E-06	9,61E-07	5,25E-07	5,03E-07	6,82E-07		9,35E-07	9,53E-07	7,14E-07	7,84E-07

Table B 4. (Continued)

FUEL SPECIMEN 11.13

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.13.1	4,72E-03	1,66E-03	7,62E-03	1,31E-05	5,75E-05	1,30E-05	5,28E-06	4,05E-06	4,37E-07	5,12E-08	6,30E-07	3,25E-07	4,38E-07	3,13E-07	4,00E-07	1,93E-05
11.13.2	9,16E-04	3,69E-04	1,75E-03	3,04E-06	3,03E-05	8,06E-06	3,39E-06	8,13E-06	9,39E-07		9,22E-08		2,91E-07	5,14E-08	1,31E-08	1,65E-06
11.13.3	6,19E-05	5,90E-05	2,23E-04	4,03E-06	1,35E-05	1,01E-05	7,11E-07	7,88E-06	7,26E-07	2,36E-09	9,47E-08	1,20E-07	5,55E-07	1,97E-08	1,25E-07	
11.13.4	5,48E-05	3,39E-05	7,11E-05	7,71E-06	1,88E-05	9,24E-06	1,43E-06	1,49E-05	1,00E-05	6,19E-07		6,33E-09	2,55E-07	2,37E-08	5,75E-08	
11.13.5	8,06E-05	7,80E-05	7,66E-05	1,45E-04	1,38E-04	8,94E-06	3,18E-06	1,10E-05	2,19E-06	1,28E-06	6,32E-07	2,34E-07	1,29E-06	3,02E-07	3,80E-07	1,06E-06
11.13.6	5,48E-05	5,02E-05	6,40E-05	7,58E-05	8,30E-05	4,57E-06	1,10E-05	1,15E-05	1,23E-06	5,27E-07	4,43E-06	6,45E-06	6,75E-06	5,07E-06	4,97E-06	4,41E-06
11.13.7	4,34E-05	3,40E-05	6,19E-05	1,21E-05	1,43E-06	3,28E-04	1,52E-05	7,00E-07	8,58E-07	5,30E-08	1,41E-08	2,28E-07	6,35E-07	9,12E-08	1,57E-07	2,22E-07
11.13.8	4,22E-05	3,16E-05	9,20E-05	9,93E-05	7,38E-06	3,32E-04	1,50E-06	2,20E-07	1,02E-07	1,87E-08		3,70E-08	1,24E-08	1,92E-08	2,91E-08	8,72E-09
11.13.9	5,11E-05	5,14E-05	7,10E-05	2,21E-05	1,91E-05	1,76E-04	5,51E-06	1,18E-05	1,15E-06	1,46E-07	4,03E-07	9,92E-07	5,72E-07	5,28E-07	3,65E-07	5,61E-07

RELEASE FRACTIONS: MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.13.1		7,81E-04	1,51E-05			<1.0E-06	1,57E-06		1,61E-06	6,50E-06					
11.13.2		6,56E-04	3,50E-05			1,32E-06	2,13E-06		1,05E-06	4,43E-06					
11.13.3		9,86E-05	5,59E-05			1,77E-05	3,30E-06		2,74E-06	6,37E-06					
11.13.4		1,59E-05	8,54E-05			5,84E-06	4,73E-06		1,96E-06	1,30E-05					
11.13.5		1,19E-05	1,13E-04			3,14E-06	2,70E-06		2,60E-06	1,57E-05					
11.13.6		8,81E-06	1,67E-05			3,33E-06	5,47E-06		2,33E-06	1,27E-05		2,63E-05			1,33E-05
11.13.7		2,46E-06					4,53E-07		1,73E-07	3,88E-07					
11.13.8		2,79E-06													
11.13.9															

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.13.1		2,37E-04	4,49E-05			2,55E-05	3,57E-05		5,44E-05	4,32E-05		3,31E-05			4,68E-05
11.13.2		1,03E-04	2,62E-05			2,06E-05	1,61E-05		3,59E-05	2,46E-05		2,22E-05			2,64E-05
11.13.3		7,10E-05	2,56E-05			4,49E-06	1,85E-05		2,08E-05	2,07E-05		1,67E-05			2,33E-05
11.13.4		2,34E-05	9,57E-06			4,61E-06	5,40E-06		6,12E-06	9,80E-06					
11.13.5		2,20E-05	1,94E-05			1,26E-05	1,49E-05		1,90E-05	2,24E-05		3,00E-05			1,53E-05
11.13.6	6,05E-06	8,56E-06	2,43E-06	5,63E-06	1,71E-06	2,07E-06	2,08E-06	2,27E-06	2,09E-06	2,34E-06	3,93E-06	4,34E-06	2,81E-06	3,08E-06	2,28E-06
11.13.7	1,39E-06	2,57E-06	7,45E-07	6,38E-07	1,11E-06	2,71E-07	2,78E-07	1,93E-06	4,66E-07	4,13E-07	1,34E-06	9,58E-07	6,28E-07	5,01E-07	3,88E-07
11.13.8		3,20E-06					8,66E-07								1,07E-06
11.13.9	2,27E-06	2,96E-06	1,32E-06	3,20E-06	1,04E-06	1,06E-06	1,84E-06	1,84E-06	2,02E-06	1,95E-06		2,83E-06	2,15E-06	1,76E-06	1,72E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.14

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.14.1	1,85E-03	6,88E-04	3,40E-03	2,88E-05	8,44E-05	5,69E-05	6,59E-05	1,91E-05	1,01E-05	2,45E-06	1,22E-06	3,60E-06	2,73E-06	1,54E-06	1,72E-06	2,81E-06
11.14.2	2,36E-03	8,52E-04	3,27E-03	2,11E-06	6,58E-06	4,71E-05	2,52E-05	3,06E-06	2,23E-05	7,28E-06		1,89E-08	5,84E-07	6,00E-08	7,32E-09	2,62E-06
11.14.3	2,92E-04	2,02E-04	3,69E-04	2,64E-05	2,22E-05	6,06E-05	6,65E-05	1,24E-07	7,20E-05	2,27E-05		2,03E-08	4,54E-07		3,11E-09	1,37E-07
11.14.4	4,85E-04	3,93E-04	5,57E-04	2,75E-04	6,02E-04	3,31E-05	5,72E-05	1,10E-04	1,34E-04	1,20E-04	5,77E-03	6,78E-05	7,77E-05	7,02E-05	7,37E-05	8,22E-05
11.14.5	3,86E-05	3,88E-05	2,29E-05	9,60E-07	6,07E-06	3,99E-05	2,97E-05	2,40E-09	1,66E-05	3,16E-06		4,17E-08	6,39E-07	2,76E-08	2,79E-08	
11.14.6	6,86E-05	6,60E-05	5,29E-05	3,63E-05	1,62E-05	2,32E-05	2,15E-05	9,53E-09	1,65E-05	1,60E-06	4,50E-07	1,08E-06	9,23E-07	1,61E-07	3,38E-07	3,00E-07
11.14.7	6,64E-04	6,59E-04	2,03E-03	1,29E-04	5,25E-06	7,40E-03	9,51E-07	3,03E-05	8,15E-07	1,17E-07	3,95E-08	2,24E-07	2,13E-07	1,24E-07	2,06E-07	8,37E-07
11.14.8	7,65E-05	6,67E-05	2,08E-04	8,95E-05	7,80E-06	1,90E-04	2,60E-07	1,12E-05	5,99E-07	3,47E-08	7,33E-08	7,77E-07	4,43E-07	4,26E-07	6,01E-07	6,69E-07
11.14.9	5,39E-05	5,42E-05	1,24E-04	8,93E-05	2,81E-05	1,26E-04	2,58E-06	8,43E-05	2,42E-06	2,13E-07		1,17E-04	5,79E-07	6,71E-07	6,01E-07	9,46E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.14.1		2,80E-04	2,71E-05			2,37E-05	6,05E-06		8,13E-06	1,19E-05					
11.14.2		1,16E-03	7,19E-05			1,24E-06	6,43E-08		1,71E-06	1,00E-06					
11.14.3		2,21E-04	3,16E-04			3,43E-06	2,57E-07		6,75E-06	1,25E-05					
11.14.4		3,98E-05	1,15E-04			9,80E-06	1,98E-05		1,95E-05	2,32E-04		1,08E-03			2,42E-04
11.14.5		1,28E-05	7,01E-05			1,86E-06	2,57E-08			1,92E-06					
11.14.6		4,01E-06	9,17E-06			2,75E-06	6,43E-08		1,23E-07	5,55E-07					
11.14.7		7,51E-05					3,73E-06		3,17E-07	6,65E-07					1,70E-06
11.14.8		6,26E-06													
11.14.9															

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.14.1		7,36E-05	1,83E-05			1,03E-05	1,57E-05		1,98E-05	1,53E-05		1,73E-05			1,41E-05
11.14.2		9,29E-05	1,04E-05			4,55E-06	8,49E-06		9,95E-06	1,35E-05		8,52E-06			1,31E-05
11.14.3		3,54E-05	8,57E-06			8,82E-07	4,50E-06		4,52E-06	7,80E-06					
11.14.4	8,09E-06	7,37E-06	1,55E-06	3,54E-06	1,83E-06	6,30E-07	8,68E-07	8,32E-07	1,53E-06	1,81E-06	2,39E-06	2,90E-06	1,97E-06	2,14E-06	2,21E-06
11.14.5	3,55E-05	2,94E-05	1,18E-05	2,21E-05	9,08E-06	7,32E-07	2,25E-07		3,76E-07	3,25E-06	6,61E-06	1,91E-06	2,91E-06	4,09E-06	4,62E-06
11.14.6	6,71E-05	6,44E-05	1,16E-05	1,53E-05	1,45E-06	5,88E-07	1,35E-07		5,63E-08	2,31E-06	3,97E-06	1,11E-06	1,97E-06	2,66E-06	3,42E-06
11.14.7	4,93E-06	2,01E-05	6,48E-07	2,15E-07	1,18E-05		9,71E-08	3,85E-08	1,81E-07	5,55E-08	3,98E-06	2,58E-06	7,70E-07	4,51E-07	
11.14.8		3,85E-06					<6,5E-07								
11.14.9	7,19E-07	2,49E-06	6,49E-06	5,10E-05	4,50E-07	6,12E-08	4,62E-05	5,24E-06	8,51E-07	8,14E-07	1,93E-06	1,63E-06	2,27E-06	2,10E-06	2,31E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.15

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.15.1	4,19E-03	1,37E-03	5,88E-03	3,71E-05	8,95E-05	1,40E-04	1,53E-05	4,82E-06	1,70E-07			3,20E-07	6,61E-07	1,52E-07	6,17E-08	7,79E-06
11.15.2	1,93E-03	7,23E-04	2,95E-03	2,28E-05	1,20E-04	1,17E-05	3,89E-06	8,11E-07		4,51E-09		8,22E-08	8,61E-07		4,59E-08	2,96E-06
11.15.3	4,96E-04	2,01E-04	8,08E-04	1,61E-05	8,76E-05	1,38E-05	1,44E-06	5,33E-07		5,61E-08		8,68E-08	4,48E-07	1,37E-08	1,86E-08	4,12E-07
11.15.4	2,03E-04	8,66E-05	1,41E-04	5,68E-05	1,50E-04	1,39E-05	3,84E-07	2,69E-07	1,24E-07	3,73E-08			6,82E-07	1,87E-09	1,89E-08	5,74E-07
11.15.5	5,83E-04	1,31E-04	4,97E-05	7,89E-05	1,94E-04	1,91E-05	7,48E-06	2,41E-07	6,79E-08	1,49E-08		9,68E-08	7,38E-07	4,56E-08	4,27E-08	9,66E-07
11.15.6	5,22E-04	1,22E-04	5,47E-05	4,27E-05	8,70E-05	1,73E-05	5,49E-06	3,73E-07		1,89E-08	2,46E-08		4,77E-07	4,99E-08	5,76E-08	
11.15.7	4,81E-04	1,22E-04	4,69E-05	2,93E-05	5,88E-05	3,02E-05	3,48E-06	5,09E-07	4,07E-07	7,83E-08	7,35E-08	2,45E-07	9,52E-08	9,90E-08	1,23E-07	5,56E-07
11.15.8	4,11E-04	1,12E-04	4,38E-05	3,28E-05	4,04E-05	8,50E-05	2,29E-06	7,49E-07	1,41E-07	1,63E-08	7,01E-08	4,27E-07	3,38E-07	1,57E-07	1,40E-07	3,73E-07
11.15.9	8,52E-04	2,31E-04	8,91E-05	8,37E-05	7,43E-05	2,65E-04	5,88E-06	7,35E-06	3,45E-07	7,99E-08	9,44E-07	5,49E-06	2,33E-06	2,94E-06	2,52E-06	4,26E-06

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.15.1		1,81E-04	5,28E-06			3,34E-06	4,04E-07		1,19E-06	2,71E-06					
11.15.2		1,22E-04	3,89E-06			6,13E-07	1,56E-07								
11.15.3		3,22E-05	4,05E-06			1,13E-06	6,22E-08								
11.15.4		5,68E-06	9,57E-06			9,53E-07	9,33E-08			7,59E-08					
11.15.5		1,86E-06	6,99E-06			<2.3E-06	1,56E-07			3,13E-07					
11.15.6		2,03E-06	1,28E-05			6,60E-07	2,80E-07		1,12E-07	7,22E-07		1,05E-06			6,48E-07
11.15.7		1,40E-06					2,49E-07		8,14E-08	1,14E-06		1,28E-06			8,39E-07
11.15.8		1,01E-06													
11.15.9															

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.15.1		1,41E-04	1,20E-04			5,27E-05	1,00E-04		1,71E-04	8,48E-05		1,07E-04			1,12E-04
11.15.2		2,69E-05	7,32E-06			6,89E-06	5,22E-06		1,12E-05	6,82E-06		5,07E-06			7,25E-06
11.15.3		1,07E-05	1,02E-05			5,82E-06	6,72E-06		7,37E-06	8,40E-06		7,42E-06			7,02E-06
11.15.4	6,16E-06	5,19E-06	5,58E-06	9,79E-06	3,46E-06	3,01E-06	3,87E-06	3,30E-06	3,86E-06	4,20E-06	5,81E-06	5,70E-06	4,51E-06	5,03E-06	4,98E-06
11.15.5	7,28E-06	5,33E-06	6,24E-06	5,17E-06	4,04E-06	3,26E-06	4,16E-06	3,93E-06	3,11E-06	4,22E-06	5,39E-06	6,64E-06	4,68E-06	4,96E-06	4,33E-06
11.15.6	1,79E-06	1,74E-06	1,00E-06	3,84E-06	1,68E-06	2,93E-07	8,01E-07	3,22E-07	6,80E-07	6,43E-07	1,25E-06	1,51E-06	8,33E-07	9,24E-07	6,86E-07
11.15.7	2,43E-06	2,67E-06	2,56E-06	8,42E-06	2,18E-06	1,05E-06	1,44E-06	1,80E-06	1,61E-06	1,56E-06	4,30E-06	4,06E-06	2,29E-06	1,98E-06	1,61E-06
11.15.8		9,14E-07					6,84E-07								6,24E-07
11.15.9	1,41E-06	1,66E-06	1,54E-06	5,63E-06	1,20E-06	4,74E-07	1,17E-06	8,76E-07	9,96E-07	2,97E-06	2,60E-06	5,30E-06	3,33E-06	2,60E-06	2,60E-06

Table B 4. (Continued)

FUEL SPECIMEN 11.16

RELEASE FRACTIONS: CENTRIFUGATES

EXPT	Rb-85	Rb-87	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.16.1	7,25E-04	2,86E-04	1,56E-03	3,85E-05	2,82E-04	7,81E-05	6,08E-05	2,18E-05	9,33E-06	2,73E-06		2,83E-07	6,47E-07	1,04E-07	2,62E-08	2,31E-06
11.16.2	3,16E-03	1,17E-03	4,23E-03	2,87E-04	4,32E-04	2,25E-05	1,70E-05	1,14E-05	1,14E-06	2,84E-06	5,69E-07	1,77E-06	5,74E-07	1,49E-06	1,46E-06	5,83E-06
11.16.3	1,64E-04	1,47E-04	1,54E-04	8,13E-05	1,61E-04	4,00E-05	3,98E-05	9,38E-06	4,15E-07	1,33E-06	4,12E-07	2,60E-06	4,23E-07	1,71E-06	2,12E-06	2,46E-06
11.16.4	1,76E-04	1,56E-04	1,40E-04	6,55E-05	1,41E-04	6,87E-05	1,06E-04	2,91E-05	1,08E-06	1,38E-06	4,56E-07	1,48E-06	4,56E-07	1,34E-06	2,01E-06	1,43E-06
11.16.5	1,63E-04	1,49E-04	1,56E-04	6,47E-05	8,95E-05	1,32E-04	2,08E-04	1,46E-05	1,41E-06	7,88E-07	3,15E-07	1,28E-06	1,02E-06	1,02E-06	1,32E-06	1,71E-06
11.16.6	2,76E-04	2,38E-04	3,23E-04	1,38E-04	3,49E-05	4,96E-04	8,89E-04	2,48E-05	4,18E-06	6,69E-07	1,81E-07	4,92E-07	3,33E-07	3,94E-07	6,43E-07	1,04E-06
11.16.7	3,02E-04	2,90E-04	3,88E-04	1,30E-04	2,93E-05	7,96E-04	1,07E-03	3,49E-05	7,94E-06	7,57E-07	4,13E-08	5,99E-07		4,13E-07	5,64E-07	8,98E-07
11.16.8	2,02E-04	1,90E-04	2,37E-04	9,08E-05	2,37E-05	3,34E-04	3,86E-04	2,44E-05	7,02E-06	6,97E-07	5,60E-08	8,82E-08	2,94E-07	3,60E-07	4,03E-07	5,98E-07
11.16.9	2,65E-04	2,67E-04	3,25E-04	1,42E-04	2,96E-05	4,07E-04	4,79E-04	3,50E-05	9,57E-06	5,99E-07	7,80E-08	2,95E-07		2,34E-07	2,67E-07	3,96E-07

RELEASE FRACTIONS:MEMBRANE FILTERS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.16.1		1,95E-04	7,67E-06			1,19E-05	4,52E-06		3,68E-06	4,63E-06					
11.16.2		2,41E-04	3,41E-05			1,06E-06	7,32E-07		7,88E-07	9,95E-07					
11.16.3		7,32E-06	1,17E-05			1,66E-06	4,66E-07			1,03E-06					
11.16.4		6,50E-06	7,57E-06			4,32E-06	9,31E-07			9,38E-07					
11.16.5		8,18E-06	8,73E-06			6,54E-06	5,85E-07			7,69E-07					
11.16.6		9,64E-06	3,58E-06			9,81E-05	7,32E-07		2,75E-08	3,09E-07					
11.16.7		6,59E-06					1,06E-06			1,47E-07					
11.16.8		3,95E-06					9,05E-07			1,10E-07					
11.16.9		9,13E-06													

RELEASE FRACTIONS: VESSEL STRIP SOLUTIONS

EXPT	Rb	Cs	Sr	Ba	Mo	Tc	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.16.1		3,20E-05	1,62E-05			7,31E-06	1,41E-05		1,92E-05	1,37E-05		1,86E-05			1,38E-05
11.16.2		3,48E-05	4,84E-06			2,37E-06	2,99E-06		3,43E-06	3,66E-06					4,52E-06
11.16.3		2,56E-06	1,66E-06			7,69E-07	1,06E-06		1,25E-06	1,49E-06					
11.16.4	1,50E-06	1,64E-06	7,07E-07	5,08E-07	5,29E-07	1,76E-06	3,98E-07	1,94E-07	2,55E-07	5,51E-07	5,55E-07	6,19E-07	3,73E-07	3,88E-07	4,20E-07
11.16.5	3,87E-06	5,91E-06	6,63E-07	1,42E-06	1,21E-06	1,05E-06	1,83E-07	1,00E-07	2,23E-07	5,30E-07	1,31E-06	1,23E-06	7,17E-07	7,97E-07	7,85E-07
11.16.6	4,90E-06	9,91E-06	8,07E-07	2,00E-06	2,51E-06	3,64E-06	2,85E-07		1,35E-07	2,75E-07	9,38E-07	1,09E-06	4,22E-07	4,23E-07	3,62E-07
11.16.7	7,05E-06	2,24E-05	1,72E-06	2,66E-06	3,79E-06	3,86E-06	3,17E-07	2,59E-07	2,82E-07	5,53E-07	8,44E-07	4,10E-07	5,30E-07	5,00E-07	5,80E-07
11.16.8		8,94E-06					7,32E-07		4,88E-07	8,63E-07					1,14E-06
11.16.9	5,28E-06	1,29E-05	1,08E-06	2,33E-06	1,86E-06	1,83E-06	1,23E-06	6,75E-07	6,81E-07	8,61E-07		3,57E-07	1,16E-06	8,38E-07	8,90E-07

TABLE C 1. Series 3 Corrosion tests: Molarities of actinides and lanthanides in centrifugates

MOLARITIES IN CENTRIFUGATES

	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.1.1	1,66E-06		3,49E-09	3,89E-13					
3.1.2	1,44E-06		6,31E-09	6,49E-13					
3.1.3	2,00E-07		4,08E-09	8,01E-14					
3.1.4	1,40E-07		9,70E-09	4,85E-13					
3.1.5	8,19E-05		3,49E-08	1,95E-10		4,15E-08			1,77E-09
3.1.6			3,11E-08	7,99E-13					
3.1.6E			1,26E-08	3,59E-13					
3.1.7			5,82E-09	4,65E-13					
3.1.8			6,79E-09	5,50E-13					1,56E-11
3.1.9	1,06E-04		1,26E-07	2,44E-09		2,40E-07			2,66E-08
3.1.10	9,39E-05			2,35E-09		3,50E-07			2,41E-08
3.1.11	1,22E-05		3,11E-10	2,25E-13					
3.1.12			1,46E-08	1,59E-13					
3.1.13			2,75E-08	4,97E-12					
3.1.14			7,76E-09	6,24E-13					
3.1.15	5,71E-12	3,75E-09	3,84E-09	2,72E-12	8,42E-10		8,30E-11	5,90E-10	6,97E-12
3.1.16	2,70E-09	9,15E-09	4,32E-09	6,31E-12	8,72E-10		3,53E-10	1,21E-09	2,98E-11

MOLARITIES IN CENTRIFUGATES

	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.2.1	2,00E-06		1,02E-09						
3.2.2	2,00E-07		1,65E-10						
3.2.3	1,58E-06		5,82E-09	2,25E-12					
3.2.4	2,00E-06		2,81E-09	5,49E-12					1,42E-10
3.2.5	2,94E-04		3,30E-07	7,99E-09		1,05E-06			8,18E-08
3.2.6	3,00E-06		6,31E-10	6,00E-13					
3.2.6E	1,48E-06		9,22E-10						
3.2.7	2,60E-06		8,73E-10	3,95E-13					2,88E-11
3.2.8	3,20E-06		6,79E-10	1,05E-13					
3.2.9	2,20E-05		4,34E-07	5,25E-09		5,41E-07			3,42E-08
3.2.10	1,20E-06		1,89E-09	7,00E-12					1,53E-10
3.2.11	6,80E-06		3,20E-10	2,09E-12					
3.2.12	2,66E-05		1,70E-10	3,10E-13					
3.2.13	8,26E-06		5,82E-10	3,90E-13					
3.2.14	1,54E-05		5,82E-10	2,49E-13					
3.2.15	1,45E-05	1,28E-09	2,25E-10	5,66E-13	7,25E-10		1,59E-11		
3.2.16	1,05E-05	2,65E-09	9,46E-10		1,45E-09		5,56E-10	1,50E-09	3,09E-10

MOLARITIES IN CENTRIFUGATES

	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.3.1	2,19E-06		2,22E-09	4,98E-13					
3.3.2	3,59E-07		3,53E-10						
3.3.3	5,18E-06		9,66E-09	3,19E-13					
3.3.4	3,39E-06		4,64E-09	1,84E-13					
3.3.5	1,41E-05		3,43E-08	8,46E-10		1,96E-07			1,14E-08
3.3.6	4,38E-06		3,19E-09	3,43E-12					
3.3.7	3,39E-06		1,21E-09	2,04E-12					8,86E-11
3.3.8	6,77E-06		1,26E-09	6,48E-12					1,95E-10
3.3.9	2,99E-05		2,13E-07	3,81E-09		5,15E-07			2,86E-08
3.3.10	7,97E-05		9,18E-09	9,97E-11		9,51E-09			1,27E-09
3.3.11	1,20E-05		6,76E-10	4,98E-12					1,91E-10
3.3.12	6,18E-05		1,06E-09	1,32E-11					3,09E-10
3.3.13	8,87E-06		7,25E-10	3,45E-12					
3.3.14	1,85E-05		7,63E-10	3,51E-12					
3.3.15	4,46E-05	1,89E-09	7,37E-10	8,11E-12	2,97E-09		1,32E-09	8,21E-09	2,90E-10
3.3.16	1,40E-05	1,36E-09	8,94E-10	3,54E-12	3,12E-09		1,69E-09	5,76E-09	4,79E-10

TABLE C 2. Series 32326 Corrosion tests: Molarities of actinides and lanthanides in centrifugates

	MOLARITIES IN CENTRIFUGATES								
	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
3.23.1	1,10E-05		3,20E-09	3,95E-13					1,76E-11
3-23.2	1,15E-05	5,26E-09	9,68E-10	4,22E-13	1,12E-10	8,82E-10	3,19E-11	2,79E-10	3,17E-11
3.23.3	5,16E-06	1,83E-09	5,24E-10	5,00E-13		5,40E-10		8,12E-11	
3.23.4	4,59E-08	2,44E-11	6,62E-11	3,35E-14	2,17E-11	4,78E-11	2,47E-11	1,36E-10	3,51E-11
3.24.1	1,30E-05		2,00E-09	1,25E-12					4,25E-11
3.24.2	2,83E-05	6,48E-09	6,30E-10	2,37E-12	2,00E-10	6,60E-10	1,32E-10	9,17E-10	1,50E-10
3-24.3	2,12E-06	1,23E-09	6,23E-10	4,00E-13	3,66E-11	5,99E-11		3,84E-10	7,02E-12
3.24.4	6,46E-08	1,79E-11	8,28E-11	4,81E-14	2,08E-11	1,97E-11	1,72E-11	1,07E-10	3,45E-11
3.24.5	4,26E-09	4,56E-11	1,76E-10		5,45E-11	7,21E-11	3,59E-11	1,77E-10	4,54E-11
3.25.1	2,02E-05		2,72E-09	3,48E-12					1,24E-10
3.25.2	3,95E-05	8,87E-09	9,79E-10	1,25E-12	3,06E-09	1,44E-08	1,80E-09	8,54E-09	5,82E-10
3.26.1	3,99E-09		2,51E-08	3,72E-12					5,90E-11
3.26.2	6,39E-09	5,09E-10	1,08E-08	4,37E-12	2,79E-08	5,46E-09	8,22E-09	4,79E-08	2,32E-09

TABLE C 3. Series 7 Corrosion tests: Molarities of actinides and lanthanides in centrifugates

	MOLARITIES IN CENTRIFUGATES								
	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
7.1.1	3,37E-06		5,24E-09	1,41E-11					5,73E-10
7.1.2	4,19E-06		2,77E-09	5,72E-12					2,75E-10
7.1.3			3,04E-08	2,44E-12					
7.2.1	4,83E-06		7,04E-09	1,24E-11					4,95E-10
7.2.2	3,58E-06		2,35E-09	3,88E-12					1,86E-10
7.2.3			1,06E-08						
7.2.4		1,70E-09	4,94E-09	4,74E-12	9,54E-10	5,46E-10	2,67E-10	7,51E-10	5,68E-11
7.3.1	4,01E-06		8,25E-09	1,62E-11					6,10E-10
7.3.2	2,59E-06		2,24E-09	3,91E-12					1,75E-10
7.3.3	7,38E-06		1,48E-09	1,97E-12					
7.4.1	4,66E-06		7,05E-09	1,40E-11					6,87E-10
7.4.2	3,18E-06		1,53E-09	2,50E-12					1,30E-10
7.4.3	1,24E-05		1,47E-09	1,30E-12					
7.4.4	2,89E-06		1,99E-09						
7.4.5	1,69E-05	3,26E-09	1,23E-09	1,12E-12	3,12E-10	1,74E-10	2,69E-10	7,01E-10	4,81E-11
7.5.1	5,57E-06		7,68E-09	1,67E-11					6,49E-10
7.5.2	3,60E-06		2,24E-09	6,27E-12					2,71E-10
7.5.3	2,40E-05		2,37E-09	5,59E-12					
7.5.4	1,70E-05	4,96E-09	1,49E-09	2,86E-12	8,40E-10		1,05E-09	3,40E-09	2,23E-10
7.6.1	6,24E-06		8,89E-09	1,21E-11					4,99E-10
7.6.2	4,01E-06		1,72E-09	5,24E-12					2,15E-10
7.6.3	9,83E-06			1,31E-12					
7.6.4	1,50E-05	3,10E-09	9,30E-10	9,33E-13	1,16E-09	2,68E-09	5,18E-10	1,16E-09	1,70E-10
7.7.1	2,41E-06		8,25E-10	2,55E-13					2,25E-11
7.7.2	1,59E-06		1,77E-09	1,56E-13					
7.7.3	9,66E-06		3,95E-10	2,25E-12					
7.8.1	1,93E-06		2,77E-10	2,45E-13					3,58E-11
7.8.2	6,37E-07		5,12E-11	3,02E-14					
7.8.3	4,78E-07								
7.9.1	1,79E-06			7,24E-14					
7.9.2	1,99E-07		3,87E-11	4,04E-13					
7.9.3	2,88E-07								
7.10.1	1,59E-06			8,31E-14					
7.10.2	3,98E-08		2,59E-10	7,27E-13		2,25E-10			
7.10.3	2,55E-07								
7.11.1	2,09E-06			5,17E-14					
7.11.2	5,97E-08		2,58E-11	1,19E-13					
7.11.3	2,23E-07	2,77E-11	1,55E-10		9,25E-10	2,14E-09	3,81E-10	8,27E-10	3,52E-10
7.12.1	3,34E-06		3,06E-09	7,26E-13					
7.12.2	4,50E-06		2,24E-11	1,40E-13					1,75E-11
7.12.3	2,94E-07	6,88E-11	1,14E-10		4,97E-10	1,08E-09	2,07E-10	3,05E-10	2,67E-10
7.13.1									
7.13.2	3,18E-06		5,40E-11	1,24E-13					
7.13.3									
7.13.4				5,18E-12					
7.13.5	1,18E-07	3,91E-12	2,59E-10		1,62E-11	9,03E-10	3,78E-10	7,06E-10	5,33E-11
7.14.1									
7.14.2	1,99E-06		3,77E-11	2,12E-14					
7.14.3									
7.14.4	5,14E-06		1,24E-10						3,89E-11

TABLE C 4. Series 11 Corrosion tests: Molarities of actinides and lanthanides in centrifugates

MOLARITIES IN CENTRIFUGATES

	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.1.1	4,77E-06	1,00E-09	6,45E-09		8,16E-11	6,57E-10	6,65E-11	4,43E-10	9,43E-11
11.1.2	4,18E-06	1,42E-10	5,96E-09		2,08E-10	9,46E-10	4,69E-11	3,17E-10	2,28E-10
11.1.3	2,61E-06	3,94E-11	2,75E-09						
11.1.4	7,64E-06	4,65E-10	5,33E-09		8,67E-10	1,05E-09		1,86E-09	1,13E-10
11.1.5	2,83E-06	8,13E-11	1,18E-09		1,84E-11	5,23E-10	1,10E-10	4,62E-10	
11.1.6	4,82E-06	1,16E-10	6,45E-10	1,03E-13		6,80E-10		5,30E-10	4,66E-11
11.1.7	8,32E-06	6,11E-10	8,29E-10		6,48E-11		7,44E-11	4,33E-10	4,33E-11
11.1.8	6,04E-06	6,19E-10	1,01E-09		1,68E-10		7,58E-11	5,00E-10	3,89E-11
11.1.9	8,83E-06	8,11E-10	7,22E-10		2,09E-10	1,03E-10	5,62E-11	3,64E-10	2,02E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.2.1	5,81E-06	1,34E-09	8,08E-09		4,19E-11	1,02E-09		5,70E-10	1,06E-10
11.2.2	4,20E-06	1,95E-10	6,59E-09		3,12E-10	8,53E-10	2,98E-10	1,55E-09	1,69E-10
11.2.3	2,07E-06	5,47E-11	2,23E-09		3,35E-10	8,20E-10	2,80E-10	7,41E-10	
11.2.4	6,19E-06	4,76E-10	5,42E-09		7,24E-10	3,07E-10	3,25E-10	2,94E-09	2,22E-11
11.2.5	3,21E-06	1,53E-10	1,26E-09		3,49E-10	8,84E-10	2,46E-10	1,79E-09	1,41E-10
11.2.6	5,73E-06	1,03E-10	5,95E-10	1,78E-12	4,44E-10	9,01E-10	4,99E-10	1,60E-09	1,72E-10
11.2.7	8,31E-06	4,32E-10	5,97E-10	9,51E-14	1,20E-10		1,14E-10	6,73E-10	6,34E-11
11.2.8	6,48E-06	4,03E-10	7,39E-10	2,71E-13	2,08E-10	8,48E-11	1,24E-10	6,44E-10	2,51E-11
11.2.9	1,07E-05	6,74E-10	5,95E-10	1,82E-13	6,85E-10	1,85E-09	2,27E-10	7,41E-10	2,83E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.3.1	4,31E-06	3,98E-10	6,61E-09		1,25E-10	1,01E-10			6,66E-10
11.3.2	3,84E-06	1,32E-10	6,81E-09	2,36E-12	1,49E-09	4,53E-10	1,11E-09	5,89E-09	4,31E-10
11.3.3	2,42E-06	3,23E-11	2,06E-09	9,59E-13	1,08E-09	1,16E-09	5,47E-10	2,57E-09	2,16E-10
11.3.4	8,81E-06	3,48E-10	3,22E-09		6,79E-10	6,30E-10	5,94E-10	3,07E-09	2,59E-10
11.3.5	3,60E-06	1,97E-10	8,83E-10	8,18E-13	4,24E-10	9,67E-10	4,01E-10	2,56E-09	1,24E-10
11.3.6	4,73E-05	6,81E-09	2,89E-08	5,29E-11	4,05E-08	6,44E-10	2,75E-08	1,41E-07	5,10E-09
11.3.7	2,35E-05	2,20E-09	8,82E-09	8,99E-12	7,64E-09		5,26E-09	2,42E-08	9,40E-10
11.3.8	7,32E-06	6,82E-10	4,88E-09	5,78E-12	3,54E-10		2,80E-09	1,27E-08	5,06E-10
11.3.9	1,10E-05	7,39E-10	3,65E-09	2,62E-12	2,41E-09	4,34E-10	1,49E-09	6,36E-09	2,38E-10

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.4.1	4,73E-06	1,43E-09	7,21E-09		5,27E-11	6,00E-10		7,06E-11	2,25E-10
11.4.2	2,60E-06	9,01E-11	5,50E-09	3,73E-12	1,59E-09	1,07E-09	1,17E-09	5,96E-09	3,30E-10
11.4.3	2,90E-06	6,86E-11	2,80E-09	2,59E-12	1,05E-09	5,84E-10	1,07E-09	5,23E-09	1,53E-10
11.4.4	7,98E-06	2,27E-10	2,74E-09	1,20E-12	1,07E-09	6,69E-10	9,01E-10	6,51E-09	4,98E-11
11.4.5	3,89E-06	2,72E-10	9,89E-10	1,15E-12	4,88E-10	9,60E-10	5,47E-10	2,96E-09	1,58E-10
11.4.6	7,34E-06	2,48E-10	5,75E-10	2,65E-12	7,52E-10	9,21E-10	3,06E-10	3,21E-09	9,94E-11
11.4.7	1,20E-05	6,73E-10	7,03E-10	3,53E-13	3,40E-10		2,40E-10	1,25E-09	7,49E-11
11.4.8	8,12E-06	6,58E-10	6,05E-10	3,49E-13	3,95E-10	5,25E-10	2,00E-10	9,86E-10	3,48E-11
11.4.9	1,26E-05	8,68E-10	5,42E-10	2,40E-13	9,71E-10	1,44E-09	2,56E-10	1,21E-09	3,71E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.5.1	3,78E-06	1,15E-09	7,05E-09		3,62E-11	7,83E-10		1,87E-11	4,28E-10
11.5.2	2,15E-06	8,04E-11	1,03E-08	7,55E-12	1,94E-09	3,94E-10	1,54E-09	8,20E-09	4,68E-10
11.5.3	1,15E-06	9,54E-12	2,35E-09	3,93E-12	1,35E-09	5,80E-10	1,02E-09	6,91E-09	1,56E-10
11.5.4	1,47E-05	1,49E-10	1,90E-09	5,39E-12	3,81E-09	4,53E-10	1,41E-09	1,04E-08	5,62E-10
11.5.5	6,96E-06	3,29E-10	1,16E-09	3,29E-12	9,40E-10	1,10E-09	6,99E-10	4,34E-09	2,32E-10
11.5.6	1,02E-05	7,90E-10	8,98E-10	3,02E-12	6,05E-10	4,98E-10	4,42E-10	2,65E-09	7,10E-11
11.5.7	1,18E-05	8,79E-10	8,90E-10	1,06E-12	5,32E-10		3,35E-10	1,74E-09	8,50E-11
11.5.8	9,69E-06	9,00E-10	8,84E-10	9,71E-13	3,94E-10	7,14E-11	2,72E-10	1,25E-09	5,72E-11
11.5.9	1,53E-05	1,22E-09	6,77E-10	5,72E-13	1,37E-09	2,21E-09	4,60E-10	1,72E-09	5,96E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.6.1	2,95E-07		5,39E-11		1,20E-10	7,46E-10		6,78E-11	2,75E-10
11.6.2	5,16E-08	5,82E-12			3,10E-10	1,64E-09		4,85E-10	
11.6.3	7,31E-08	4,98E-12			6,89E-11	8,67E-10	1,35E-11	3,80E-11	1,41E-11
11.6.4	4,80E-08	9,42E-12			4,62E-11	6,03E-10	2,42E-11	4,23E-11	6,65E-11
11.6.5	2,83E-08	7,31E-12	3,10E-11		1,06E-10	1,09E-09	1,56E-11	1,89E-10	5,67E-11
11.6.6	2,84E-08	4,56E-12	1,06E-10	8,41E-14		6,37E-10	1,68E-11		
11.6.7	2,72E-08	4,98E-11	1,94E-10		1,04E-10	1,56E-10	6,13E-11	2,84E-10	5,77E-11
11.6.8	6,06E-08	5,18E-12	3,14E-11		7,36E-13	3,40E+06	7,57E-13	9,14E-12	1,40E-11
11.6.9	6,17E-07	2,19E-11	5,03E-11	1,80E-12	1,05E-09	1,03E-09	3,97E-10	1,23E-09	7,33E-11

TABLE C 4. Series 11 Corrosion tests: Molarities of actinides and lanthanides in centrifugates

MOLARITIES IN CENTRIFUGATES

	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.7.1	3,22E-06	2,05E-09	1,49E-08		1,49E-10	1,04E-11			1,65E-09
11.7.2	7,56E-07	3,83E-09	2,69E-08	1,54E-12	3,70E-10	1,33E-09		2,22E-10	
11.7.3	6,65E-06	1,24E-09	1,01E-08	3,33E-12	1,42E-09	8,68E-10	8,20E-10	4,27E-09	2,06E-10
11.7.4	3,62E-05	1,47E-08	2,61E-07	6,41E-10	1,69E-08	2,93E-08	1,71E-08	7,97E-08	1,78E-09
11.7.5	8,19E-09	3,63E-09	1,32E-08	1,71E-12	3,81E-10	1,34E-09	3,18E-10	1,63E-09	1,14E-10
11.7.6	1,64E-09	2,10E-09	8,05E-09	3,93E-11	1,34E-08	1,53E-09	4,97E-09	2,52E-08	4,70E-10
11.7.7	3,09E-05	1,82E-10	4,95E-10	3,07E-12	2,20E-10	4,47E-10	1,76E-10	9,07E-10	9,71E-11
11.7.8	2,83E-06	5,46E-11	2,93E-11		2,16E-10	1,80E-10	7,13E-11	4,04E-10	1,35E-11
11.7.9	1,29E-05	9,18E-11	2,35E-10	3,34E-12	6,53E-10	9,18E-10	4,91E-10	1,99E-09	9,35E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.8.1	3,57E-06	4,29E-10	3,64E-09	1,04E-12	2,68E-10	9,17E-10	7,69E-11	4,92E-10	1,47E-09
11.8.2	1,87E-06	1,01E-10	5,99E-09	1,01E-11	2,40E-09	1,52E-09	1,20E-09	6,34E-09	2,25E-10
11.8.3	1,11E-06	2,05E-11	1,87E-09	3,45E-12	1,33E-09	5,33E-10	1,09E-09	6,41E-09	2,02E-10
11.8.4	1,12E-05	1,18E-10	1,77E-09	2,79E-12	1,45E-09	3,54E-10	1,07E-09	7,36E-09	1,84E-10
11.8.5	6,28E-06	4,17E-10	9,36E-10	4,47E-12	9,26E-10	8,89E-10	8,32E-10	4,80E-09	2,50E-10
11.8.6	1,09E-05	6,61E-10	7,93E-10	4,50E-12	8,60E-10	4,36E-10	5,37E-10	3,42E-09	1,62E-10
11.8.7	1,51E-05	1,27E-09	9,21E-10	1,43E-12	6,41E-10		4,33E-10	2,20E-09	1,20E-10
11.8.8	9,23E-06	1,08E-09	8,29E-10	1,81E-12	4,72E-10		2,83E-10	1,44E-09	6,80E-11
11.8.9	1,35E-05	1,50E-09	8,13E-10	1,81E-12	3,73E-10		2,58E-10	1,24E-09	6,42E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.9.1	4,04E-07		1,49E-11		6,79E-11	8,52E-10	1,71E-11	1,14E-10	1,56E-10
11.9.2	9,21E-08	2,82E-11	1,01E-11		6,67E-11	8,68E-10	6,59E-11	2,25E-10	1,94E-11
11.9.3	4,69E-08	4,56E-12			3,95E-10	1,48E-09	6,76E-11	1,66E-10	
11.9.4	3,92E-08					1,22E-09	7,74E-11	1,74E-10	1,13E-10
11.9.5	4,94E-08	5,93E-12			6,82E-11	7,63E-10		5,81E-11	1,10E-10
11.9.6	5,78E-08	9,62E-12	4,12E-11	5,37E-13	1,98E-10	1,05E-09	8,01E-11	3,70E-10	6,89E-11
11.9.7	9,43E-08	5,21E-11	1,72E-10	5,21E-13	6,33E-11	9,29E-11	4,85E-11	2,71E-10	5,85E-11
11.9.8	1,19E-07	9,70E-12	2,78E-11		9,18E-11	8,60E-11	3,34E-11	1,42E-10	3,62E-11
11.9.9	4,55E-06	7,21E-11	1,05E-10	6,52E-12	1,44E-09	1,95E-09	7,65E-10	2,22E-09	9,86E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.10.1	5,45E-06	1,98E-09	8,23E-09		8,02E-10	1,46E-09	1,12E-10	6,40E-10	1,69E-09
11.10.2	1,80E-06	2,35E-10	5,83E-09	2,02E-11	2,54E-09	5,19E-10	1,49E-09	8,94E-09	5,59E-10
11.10.3	2,37E-06	1,88E-10	4,40E-09	1,53E-11	2,84E-09	9,02E-10	2,45E-09	1,14E-08	4,42E-10
11.10.4	6,15E-06	2,03E-10	3,68E-09	1,25E-11	3,29E-09	8,00E-10	2,29E-09	1,06E-08	2,77E-10
11.10.5	3,78E-06	2,70E-10	1,60E-09	1,24E-11	1,74E-09	1,04E-09	1,42E-09	8,09E-09	3,12E-10
11.10.6	7,65E-06	1,58E-09	1,13E-09	9,99E-12	1,40E-09	7,64E-10	1,07E-09	6,20E-09	2,29E-10
11.10.7	9,85E-06	1,25E-09	1,39E-09	2,11E-12	1,04E-10		7,27E-10	3,56E-09	1,69E-10
11.10.8	6,94E-06	1,11E-09	1,08E-09	2,37E-12	4,64E-10		3,06E-10	1,57E-09	7,47E-11
11.10.9	1,12E-05	1,70E-09	9,53E-10	1,70E-12	3,51E-10		2,63E-10	1,16E-09	6,63E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.11.1	5,03E-06	1,15E-09	6,32E-09		2,35E-10	8,49E-10	5,03E-11	1,58E-10	1,94E-10
11.11.2	1,59E-06	7,54E-11	5,07E-09	5,78E-11	5,85E-09	1,29E-09	5,21E-09	2,60E-08	1,54E-09
11.11.3	5,28E-06	7,62E-11	5,69E-09	1,08E-11	2,53E-09	4,39E-10	2,52E-09	1,12E-08	3,81E-10
11.11.4	9,83E-06	2,96E-10	3,85E-09	8,41E-12	1,60E-09	8,39E-10	1,17E-09	7,41E-09	4,37E-10
11.11.5	5,52E-06	2,37E-10	2,29E-09	8,59E-12	1,22E-09	1,05E-09	1,06E-09	6,20E-09	3,18E-10
11.11.6	8,97E-06	1,06E-09	1,23E-09	5,79E-12	7,76E-10	3,77E-10	4,98E-10	2,75E-09	1,44E-10
11.11.7	1,13E-05	1,33E-09	1,85E-09	2,27E-12	5,87E-10		4,67E-10	2,26E-09	1,31E-10
11.11.8	7,95E-06	1,08E-09	1,28E-09	2,09E-12	4,11E-10	2,13E-11	2,58E-10	1,28E-09	5,75E-11
11.11.9	1,15E-05	1,37E-09	1,11E-09	1,56E-12	3,10E-10	2,82E-11	1,79E-10	7,41E-10	3,93E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.12.1	7,75E-06	2,33E-09	8,79E-09		5,35E-11	2,70E-10	2,67E-11	2,30E-10	6,34E-10
11.12.2	2,59E-06	1,11E-10	9,34E-09	9,73E-12	2,18E-09	5,87E-10	2,05E-09	9,39E-09	8,36E-10
11.12.3	1,75E-06	6,14E-11	2,70E-09	7,88E-12	1,72E-09	1,28E-09	1,69E-09	7,39E-09	2,47E-10
11.12.4	8,59E-06	1,40E-10	3,66E-09	1,04E-11	1,90E-09	6,57E-10	1,65E-09	8,18E-09	3,06E-10
11.12.5	3,79E-06	2,49E-10	1,86E-09	1,03E-11	1,82E-09	1,22E-09	1,42E-09	7,84E-09	3,54E-10
11.12.6	7,54E-06	1,11E-09	1,39E-09	9,19E-12	1,21E-09	1,30E-09	8,96E-10	5,23E-09	
11.12.7	9,93E-06	1,14E-09	1,69E-09	3,76E-12	6,27E-10		5,41E-10	2,70E-09	1,24E-10
11.12.8	7,49E-06	1,07E-09	1,36E-09	2,09E-12	2,58E-10		2,54E-10	1,11E-09	6,61E-11
11.12.9	1,09E-05	1,48E-09	1,17E-09	2,46E-12	3,05E-10		3,07E-10	1,31E-09	6,51E-11

TABLE C 4. Series 11 Corrosion tests: Molarities of actinides and lanthanides in centrifugates

MOLARITIES IN CENTRIFUGATES

	ACTINIDES				LANTHANIDES				
EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.13.1	1,23E-06	6,99E-11	1,50E-10	1,53E-11	2,90E-10	7,83E-10	3,02E-10	1,54E-09	2,57E-09
11.13.2	2,47E-06	1,50E-10		2,24E-12		4,98E-10	4,92E-11	5,03E-11	2,20E-10
11.13.3	2,39E-06	1,16E-10	6,90E-12	2,31E-12	1,07E-10	9,49E-10	1,89E-11	4,80E-10	
11.13.4	4,53E-06	1,61E-09	1,81E-09		5,65E-12	4,37E-10	2,27E-11	2,21E-10	
11.13.5	3,33E-06	3,51E-10	3,73E-09	1,54E-11	2,09E-10	2,21E-09	2,90E-10	1,46E-09	1,42E-10
11.13.6	3,49E-06	1,97E-10	1,54E-09	1,08E-10	5,75E-09	1,15E-08	4,86E-09	1,91E-08	5,88E-10
11.13.7	2,12E-07	1,37E-10	1,55E-10	3,44E-13	2,03E-10	1,09E-09	8,74E-11	6,03E-10	2,96E-11
11.13.8	6,68E-08	1,63E-11	5,48E-11		3,30E-11	2,12E-11	1,84E-11	1,12E-10	1,16E-12
11.13.9	3,58E-06	1,84E-10	4,27E-10	9,81E-12	8,85E-10	9,78E-10	5,06E-10	1,40E-09	7,49E-11

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.14.1	5,75E-06	1,61E-09	7,15E-09	3,10E-11	3,22E-09	4,69E-09	1,49E-09	6,64E-09	3,78E-10
11.14.2	9,23E-07	3,57E-09	2,13E-08		1,69E-11	1,00E-09	5,77E-11	2,90E-11	3,52E-10
11.14.3	3,73E-08	1,16E-08	6,63E-08		1,82E-11	7,80E-10		1,20E-11	1,84E-11
11.14.4	3,33E-05	2,15E-08	3,50E-07	1,47E-09	6,08E-08	1,33E-07	6,75E-08	2,84E-07	1,10E-08
11.14.5	7,25E-10	2,67E-09	9,23E-09		3,73E-11	1,13E-09	2,65E-11	1,08E-10	
11.14.6	2,88E-09	2,66E-09	4,68E-09	1,15E-11	9,64E-10	1,59E-09	1,55E-10	1,30E-09	4,04E-11
11.14.7	9,15E-06	1,31E-10	3,42E-10	1,01E-12	2,01E-10	3,66E-10	1,19E-10	7,95E-10	1,15E-10
11.14.8	3,38E-06	9,61E-11	1,01E-10	1,87E-12	6,96E-10	7,61E-10	4,09E-10	2,32E-09	8,99E-11
11.14.9	2,54E-05	3,88E-10	6,22E-10		1,05E-07	9,94E-10	6,46E-10	2,32E-09	1,27E-10

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.15.1	1,50E-06	2,84E-11			2,98E-10	1,19E-09	1,52E-10	2,47E-10	1,09E-09
11.15.2	2,53E-07		1,37E-11		7,66E-11	1,54E-09		1,84E-10	4,14E-10
11.15.3	1,66E-07		1,70E-10		8,09E-11	7,99E-10	1,37E-11	7,46E-11	5,76E-11
11.15.4	8,39E-08	2,06E-11	1,13E-10			1,22E-09	1,87E-12	7,58E-11	8,02E-11
11.15.5	7,50E-08	1,13E-11	4,50E-11		9,01E-11	1,32E-09	4,56E-11	1,71E-10	1,35E-10
11.15.6	1,16E-07		5,72E-11	6,68E-13		8,51E-10	4,99E-11	2,31E-10	
11.15.7	1,59E-07	6,78E-11	2,37E-10	2,05E-12	2,28E-10	1,70E-10	9,90E-11	4,93E-10	7,78E-11
11.15.8	2,34E-07	2,35E-11	4,94E-11	1,90E-12	3,98E-10	6,03E-10	1,57E-10	5,62E-10	5,22E-11
11.15.9	2,29E-06	5,75E-11	2,42E-10	2,57E-11	5,11E-09	4,16E-09	2,94E-09	1,01E-08	5,96E-10

EXPT	U	Np	Pu	Cm	La	Ce	Pr	Nd	Eu
11.16.1	6,63E-06	1,52E-09	8,07E-09		2,59E-10	1,13E-09	1,02E-10	1,03E-10	3,18E-10
11.16.2	3,45E-06	1,86E-10	8,40E-09	1,60E-11	1,62E-09	1,01E-09	1,46E-09	5,75E-09	8,02E-10
11.16.3	2,85E-06	6,78E-11	3,94E-09	1,16E-11	2,38E-09	7,41E-10	1,68E-09	8,34E-09	3,38E-10
11.16.4	8,82E-06	1,77E-10	4,09E-09	1,28E-11	1,35E-09	7,99E-10	1,32E-09	7,91E-09	1,97E-10
11.16.5	4,44E-06	2,30E-10	2,33E-09	8,84E-12	1,17E-09	1,79E-09	1,00E-09	5,20E-09	2,35E-10
11.16.6	7,52E-06	6,83E-10	1,98E-09	5,07E-12	4,50E-10	5,84E-10	3,87E-10	2,53E-09	1,42E-10
11.16.7	1,06E-05	1,30E-09	2,24E-09	1,16E-12	5,47E-10		4,05E-10	2,22E-09	1,23E-10
11.16.8	7,39E-06	1,15E-09	2,06E-09	1,57E-12	8,06E-11	5,15E-10	3,53E-10	1,59E-09	8,22E-11
11.16.9	1,06E-05	1,56E-09	1,77E-09	2,19E-12	2,70E-10		2,30E-10	1,05E-09	5,44E-11

Table D 1. Series 3 Corrosion tests Specimen inventories (ICP-MS) of selected nuclides and elements

NUCLIDES

	MICROGRAMS/SPECIMEN		
Wt.U Init (g)	13,11	14,32	14,57
B.U.	42,0	42,0	42,0
NUCL	3-1	3-2	3-3
Rb-85	1923,5	2101,0	2137,7
Rb-87	4204,9	4593,0	4673,2
Sr-88	5221,6	5703,5	5803,1
Sr-90	6896,2	7532,6	7664,2
Y-89	6834,0	7464,8	7595,1
Zr-93	11135,6	12163,4	12375,8
Mo-95	11774,1	12860,8	13085,3
Mo-97	12857,0	14043,6	14288,8
Mo-98	13385,3	14620,7	14876,0
Mo-100	15430,5	16854,6	17148,9
Tc-99	12360,1	13500,9	13736,6
Ru-101	12774,4	13953,4	14197,0
Rh-103	6995,5	7641,2	7774,6
Cs-133	19904,0	21741,1	22120,7
Cs-135	7706,9	8418,2	8565,1
Cs-137	18736,5	20465,8	20823,1
Ba-138	23059,6	25187,9	25627,6
La-139	21384,7	23358,4	23766,2
Ce-140	19702,8	21521,3	21897,1
Pr-141	18796,3	20531,1	20889,5
Nd-143	13047,6	14251,9	14500,7
Nd-144	27668,2	30221,8	30749,4
Nd-145	12688,3	13859,3	14101,3
Nd-146	14062,7	15360,7	15628,9
Sm-152	2043,9	2232,6	2271,5
Eu-153	2441,8	2667,1	2713,7
Gd-156	2810,3	3069,7	3123,2
Np-237	6593,8	7202,4	7328,2
Pu-239	65032,0	71034,2	72274,4
Pu-240	35927,3	39243,3	39928,4
Pu-241	8586,6	9379,1	9542,9
Pu-242	9915,9	10831,1	11020,2
Am-241	9519,8	10398,5	10580,0
Am-243	2131,0	2327,7	2368,3
Cm-244	543,8	594,0	604,3
TOTAL U *	1,245E+07	1,360E+07	1,384E+07

* After irradiation

ELEMENTS

	MOLES/SPECIMEN		
SPECIMEN	3-1	3-2	3-3
Wt.U Init (g)	13,11	14,32	14,57
U	5,23E-02	5,72E-02	5,82E-02
Np	2,78E-05	3,04E-05	3,09E-05
Pu	5,19E-04	5,67E-04	5,77E-04
Cm	2,40E-06	2,62E-06	2,66E-06
La	1,54E-04	1,68E-04	1,71E-04
Ce	2,65E-04	2,89E-04	2,94E-04
Pr	1,33E-04	1,46E-04	1,48E-04
Nd	5,44E-04	5,94E-04	6,04E-04
Eu	1,99E-05	2,18E-05	2,21E-05

Table D 2. Series 32326 Corrosion tests Specimen inventories (ICP-MS) of selected nuclides and elements

NUCLIDES

	MICROGRAMS/SPECIMEN			
Wt.U Init (g)	0,864	0,872	0,987	0,992
B.U.	42,0	42,0	42,0	42,0
NUCL	3-23	3-24	3-25	3-26
Rb-85	126,8	127,9	144,8	145,5
Rb-87	277,2	279,6	316,5	318,1
Sr-88	344,2	347,2	393,1	395,1
Sr-90	454,5	458,5	519,1	521,8
Y-89	450,4	454,4	514,5	517,1
Zr-93	734,0	740,4	838,3	842,5
Mo-95	776,0	782,9	886,3	890,8
Mo-97	847,4	854,9	967,9	972,8
Mo-98	882,2	890,0	1007,6	1012,7
Mo-100	1017,0	1026,0	1161,6	1167,5
Tc-99	814,7	821,8	930,4	935,2
Ru-101	842,0	849,4	961,6	966,5
Rh-103	461,1	465,1	526,6	529,3
Cs-133	1311,9	1323,4	1498,3	1505,9
Cs-135	508,0	512,4	580,2	583,1
Cs-137	1235,0	1245,8	1410,5	1417,6
Ba-138	1519,9	1533,3	1735,9	1744,7
La-139	1409,5	1421,9	1609,8	1618,0
Ce-140	1298,6	1310,1	1483,2	1490,7
Pr-141	1238,9	1249,8	1415,0	1422,1
Nd-143	860,0	867,6	982,2	987,2
Nd-144	1823,6	1839,7	2082,8	2093,4
Nd-145	836,3	843,7	955,2	960,0
Nd-146	926,9	935,0	1058,6	1064,0
Sm-152	134,7	135,9	153,9	154,6
Eu-153	160,9	162,4	183,8	184,7
Gd-156	185,2	186,9	211,6	212,6
Np-237	434,6	438,4	496,4	498,9
Pu-239	4286,4	4324,1	4895,5	4920,3
Pu-240	2368,0	2388,9	2704,6	2718,3
Pu-241	566,0	570,9	646,4	649,7
Pu-242	653,6	659,3	746,5	750,2
Am-241	627,5	633,0	716,6	720,3
Am-243	140,5	141,7	160,4	161,2
Cm-244	35,8	36,2	40,9	41,1
TOTAL U *	8,209E+05	8,281E+05	9,376E+05	9,423E+05

ELEMENTS

	MOLES/SPECIMEN			
SPECIMEN	3-23	3-24	3-25	3-26
Wt.U Init (g)	0,864	0,872	0,987	0,992
U	3,45E-03	3,48E-03	3,94E-03	3,96E-03
Np	1,83E-06	1,85E-06	2,09E-06	2,10E-06
Pu	3,42E-05	3,45E-05	3,91E-05	3,93E-05
Cm	1,58E-07	1,59E-07	1,80E-07	1,81E-07
La	1,01E-05	1,02E-05	1,16E-05	1,16E-05
Ce	1,75E-05	1,76E-05	1,99E-05	2,00E-05
Pr	8,79E-06	8,87E-06	1,00E-05	1,01E-05
Nd	3,58E-05	3,62E-05	4,09E-05	4,11E-05
Eu	1,31E-06	1,32E-06	1,50E-06	1,51E-06

Table D 3. Series 7 Corrosion tests
Specimen inventories (ICP-MS) of selected nuclides and elements

NUCLIDES

	MICROGRAMS/SPECIMEN						
Wt.U Init (g)	10,69	10,56	10,39	10,67	10,41	10,45	10,38
B.U.	43,0	43,0	43,0	43,0	43,0	43,0	43,0
NUCL	7-1	7-2	7-3	7-4	7-5	7-6	7-7
Rb-85	1511,2	1492,9	1468,8	1508,4	1471,7	1477,3	1467,4
Rb-87	3321,8	3281,4	3228,6	3315,6	3234,8	3247,2	3225,5
Sr-88	4452,1	4397,9	4327,1	4443,8	4335,5	4352,1	4323,0
Sr-90	5787,9	5717,5	5625,5	5777,1	5636,3	5657,9	5620,0
Y-89	5869,9	5798,5	5705,2	5858,9	5716,1	5738,1	5699,7
Zr-93	8608,4	8503,7	8366,8	8592,3	8383,0	8415,2	8358,8
Mo-95	9230,1	9117,9	8971,1	9212,9	8988,4	9022,9	8962,5
Mo-97	10045,6	9923,4	9763,7	10026,8	9782,5	9820,0	9754,3
Mo-98	10631,4	10502,2	10333,1	10611,6	10353,0	10392,8	10323,1
Mo-100	11699,3	11557,0	11370,9	11677,4	11392,8	11436,6	11360,0
Tc-99	10521,5	10393,5	10226,2	10501,8	10245,9	10285,3	10216,4
Ru-101	8108,3	8009,7	7880,7	8093,1	7895,9	7926,3	7873,2
Rh-103	5198,0	5134,8	5052,1	5188,3	5061,8	5081,3	5047,2
Cs-133	15810,1	15617,9	15366,5	15780,6	15396,0	15455,2	15351,7
Cs-135	5140,8	5078,3	4996,6	5131,2	5006,2	5025,4	4991,8
Cs-137	14695,6	14516,9	14283,2	14668,1	14310,7	14365,7	14269,5
Ba-138	18446,6	18222,3	17928,9	18412,1	17963,4	18032,5	17911,7
La-139	16922,9	16717,1	16448,0	16891,2	16479,6	16543,0	16432,1
Ce-140	16841,7	16636,8	16369,0	16810,1	16400,5	16463,5	16353,3
Pr-141	18164,5	17943,6	17654,8	18130,6	17688,8	17756,7	17637,8
Nd-143	13062,2	12903,3	12695,6	13037,8	12720,1	12768,9	12683,4
Nd-144	25225,4	24918,6	24517,5	25178,2	24564,7	24659,0	24493,9
Nd-145	12089,2	11942,2	11749,9	12066,6	11772,5	11817,8	11738,6
Nd-146	13010,6	12852,4	12645,5	12986,3	12669,8	12718,5	12633,3
Sm-152	1996,1	1971,8	1940,1	1992,3	1943,8	1951,3	1938,2
Eu-153	2296,3	2268,4	2231,9	2292,0	2236,2	2244,8	2229,7
Gd-156	2216,3	2189,4	2154,1	2212,2	2158,3	2166,6	2152,1
Np-237	5689,6	5620,4	5529,9	5678,9	5540,5	5561,8	5524,6
Pu-239	58008,8	57303,4	56380,9	57900,3	56489,4	56706,5	56326,6
Pu-240	29932,3	29568,3	29092,3	29876,3	29148,3	29260,3	29064,3
Pu-241	9847,7	9728,0	9571,4	9829,3	9589,8	9626,6	9562,2
Pu-242	8201,5	8101,7	7971,3	8186,1	7986,6	8017,3	7963,6
Am-241	6567,7	6487,9	6383,4	6555,5	6395,7	6420,3	6377,3
Am-243	1635,9	1616,1	1590,0	1632,9	1593,1	1599,2	1588,5
Cm-244	434,3	429,0	422,1	433,5	422,9	424,5	421,7
TOTAL U *	1,016E+07	1,003E+07	9,871E+06	1,014E+07	9,890E+06	9,928E+06	9,861E+06

ELEMENTS

	MOLES/SPECIMEN						
SPECIMEN	7.1	7.2	7.3	7.4	7.5	7.6	7.7
Wt.U Init (g)	10,69	10,56	10,39	10,67	10,41	10,45	10,38
U	4,27E-02	4,22E-02	4,15E-02	4,26E-02	4,16E-02	4,17E-02	4,14E-02
Np	2,40E-05	2,37E-05	2,33E-05	2,40E-05	2,34E-05	2,35E-05	2,33E-05
Pu	4,88E-04	4,82E-04	4,74E-04	4,87E-04	4,75E-04	4,77E-04	4,74E-04
Cm	1,78E-06	1,76E-06	1,73E-06	1,78E-06	1,73E-06	1,74E-06	1,73E-06
La	1,22E-04	1,20E-04	1,18E-04	1,22E-04	1,19E-04	1,19E-04	1,18E-04
Ce	2,28E-04	2,26E-04	2,22E-04	2,28E-04	2,22E-04	2,23E-04	2,22E-04
Pr	1,29E-04	1,27E-04	1,25E-04	1,29E-04	1,25E-04	1,26E-04	1,25E-04
Nd	5,10E-04	5,04E-04	4,96E-04	5,10E-04	4,97E-04	4,99E-04	4,96E-04
Eu	1,80E-05	1,77E-05	1,75E-05	1,79E-05	1,75E-05	1,76E-05	1,74E-05

Table D 3. (Continued) Series 7 Corrosion tests
Specimen inventories (ICP-MS) of selected nuclides and elements

NUCLIDES

	MICROGRAMS/SPECIMEN						
Wt.U Init (g)	10,38	10,57	10,48	10,57	10,47	9,95	10,08
B.U.	43,0	43,0	43,0	43,0	43,0	43,0	43,0
NUCL	7-8	7-9	7-10	7-11	7-12	7-13	7-14
Rb-85	1467,4	1494,3	1481,6	1494,3	1480,1	1406,6	1425,0
Rb-87	3225,5	3284,5	3256,6	3284,5	3253,5	3091,9	3132,3
Sr-88	4323,0	4402,1	4364,6	4402,1	4360,5	4143,9	4198,0
Sr-90	5620,0	5722,9	5674,2	5722,9	5668,8	5387,2	5457,6
Y-89	5699,7	5804,0	5754,6	5804,0	5749,1	5463,6	5534,9
Zr-93	8358,8	8511,8	8439,3	8511,8	8431,3	8012,5	8117,2
Mo-95	8962,5	9126,5	9048,8	9126,5	9040,2	8591,2	8703,4
Mo-97	9754,3	9932,8	9848,2	9932,8	9838,8	9350,2	9472,3
Mo-98	10323,1	10512,1	10422,6	10512,1	10412,7	9895,5	10024,8
Mo-100	11360,0	11567,9	11469,4	11567,9	11458,5	10889,4	11031,7
Tc-99	10216,4	10403,4	10314,8	10403,4	10305,0	9793,2	9921,1
Ru-101	7873,2	8017,3	7949,0	8017,3	7941,4	7547,0	7645,6
Rh-103	5047,2	5139,6	5095,9	5139,6	5091,0	4838,2	4901,4
Cs-133	15351,7	15632,7	15499,6	15632,7	15484,8	14715,7	14908,0
Cs-135	4991,8	5083,1	5039,8	5083,1	5035,0	4785,0	4847,5
Cs-137	14269,5	14530,7	14406,9	14530,7	14393,2	13678,3	13857,1
Ba-138	17911,7	18239,5	18084,2	18239,5	18067,0	17169,7	17394,0
La-139	16432,1	16732,9	16590,4	16732,9	16574,6	15751,4	15957,2
Ce-140	16353,3	16652,6	16510,8	16652,6	16495,0	15675,8	15880,6
Pr-141	17637,8	17960,6	17807,7	17960,6	17790,7	16907,1	17128,0
Nd-143	12683,4	12915,6	12805,6	12915,6	12793,4	12158,0	12316,8
Nd-144	24493,9	24942,2	24729,8	24942,2	24706,2	23479,2	23786,0
Nd-145	11738,6	11953,5	11851,7	11953,5	11840,4	11252,3	11399,3
Nd-146	12633,3	12864,6	12755,0	12864,6	12742,9	12110,0	12268,2
Sm-152	1938,2	1973,7	1956,9	1973,7	1955,0	1857,9	1882,2
Eu-153	2229,7	2270,5	2251,2	2270,5	2249,1	2137,4	2165,3
Gd-156	2152,1	2191,4	2172,8	2191,4	2170,7	2062,9	2089,9
Np-237	5524,6	5625,7	5577,8	5625,7	5572,5	5295,7	5364,9
Pu-239	56326,6	57357,7	56869,3	57357,7	56815,0	53993,3	54698,7
Pu-240	29064,3	29596,3	29344,3	29596,3	29316,3	27860,3	28224,3
Pu-241	9562,2	9737,2	9654,3	9737,2	9645,1	9166,0	9285,8
Pu-242	7963,6	8109,4	8040,3	8109,4	8032,7	7633,7	7733,5
Am-241	6377,3	6494,0	6438,7	6494,0	6432,6	6113,1	6193,0
Am-243	1588,5	1617,6	1603,8	1617,6	1602,3	1522,7	1542,6
Cm-244	421,7	429,4	425,8	429,4	425,4	404,2	409,5
TOTAL U *	9,861E+06	1,004E+07	9,956E+06	1,004E+07	9,947E+06	9,453E+06	9,576E+06

ELEMENTS

	MOLES/SPECIMEN						
SPECIMEN	7.8	7.9	7.10	7.11	7.12	7.13	7.14
Wt.U Init (g)	10,38	10,56	10,48	10,57	10,47	9,95	10,08
U	4,14E-02	4,22E-02	4,18E-02	4,22E-02	4,18E-02	3,97E-02	4,02E-02
Np	2,33E-05	2,37E-05	2,35E-05	2,37E-05	2,35E-05	2,23E-05	2,26E-05
Pu	4,74E-04	4,82E-04	4,78E-04	4,82E-04	4,78E-04	4,54E-04	4,60E-04
Cm	1,73E-06	1,76E-06	1,74E-06	1,76E-06	1,74E-06	1,66E-06	1,68E-06
La	1,18E-04	1,20E-04	1,19E-04	1,20E-04	1,19E-04	1,13E-04	1,15E-04
Ce	2,22E-04	2,26E-04	2,24E-04	2,26E-04	2,24E-04	2,13E-04	2,15E-04
Pr	1,25E-04	1,27E-04	1,26E-04	1,27E-04	1,26E-04	1,20E-04	1,21E-04
Nd	4,96E-04	5,04E-04	5,00E-04	5,05E-04	5,00E-04	4,75E-04	4,81E-04
Eu	1,74E-05	1,77E-05	1,76E-05	1,78E-05	1,76E-05	1,67E-05	1,69E-05

Table D 4. Series 11 Corrosion tests
Specimen inventories (ICP-MS) of selected nuclides and elements

NUCLIDES

	MICROGRAMS/SPECIMEN							
Wt.U Init (g)	13,943	15,926	16,033	14,793	15,012	15,199	17,083	12,594
B.U.	27,0	30,1	32,7	34,9	40,1	41,4	42,7	43,8
NUCL	**11-1**	**11-2**	**11-3**	**11-4**	**11-5**	**11-6**	**11-7**	**11-8**
Rb-85	1343,2	1630,7	1723,2	1653,5	1830,6	1892,1	2170,0	1626,9
Rb-87	2970,3	3599,6	3798,5	3641,1	4022,1	4155,1	4763,2	3569,6
Sr-88	3896,6	4736,6	5009,8	4810,7	5333,9	5514,7	6326,8	4744,5
Sr-90	5222,4	6318,0	6658,5	6376,2	7028,6	7257,4	8315,7	6229,6
Y-89	5334,7	6490,3	6868,9	6599,3	7324,4	7574,5	8691,9	6519,2
Zr-93	7983,3	9862,8	10557,3	10231,3	11559,3	12001,1	13823,5	10399,8
Mo-95	8527,3	10521,4	11251,8	10896,7	12293,4	12759,3	14692,3	11050,8
Mo-97	8895,9	11123,2	12010,2	11715,5	13410,0	13962,1	16125,5	12158,0
Mo-98	9147,9	11468,5	12406,4	12119,0	13910,5	14491,8	16746,8	12632,2
Mo-100	10362,1	13037,7	14140,1	13838,8	15944,0	16623,7	19224,9	14510,3
Tc-99	8831,4	10903,3	11665,4	11301,0	12758,4	13243,9	15252,5	11473,5
Ru-101	8602,6	10804,0	11702,3	11441,9	13157,6	13712,8	15852,5	11961,3
Rh-103	5068,7	6102,5	6407,6	6118,3	6703,5	6912,2	7909,8	5919,0
Cs-133	13584,4	16540,2	17515,7	16835,9	18704,0	19346,7	22205,3	16657,6
Cs-135	5958,8	6913,4	7050,3	6575,6	6842,4	6970,5	7882,7	5841,4
Cs-137	11265,1	14151,1	15330,2	14990,8	17242,6	17971,2	20776,4	15677,1
Ba-138	14632,4	18299,4	19761,4	19278,5	22071,5	22981,2	26543,3	20013,3
La-139	13751,0	17147,3	18478,8	17999,2	20543,4	21375,9	24673,5	18594,1
Ce-140	13738,0	17188,5	18567,6	18118,1	20752,6	21610,1	24962,0	18822,5
Pr-141	15101,0	18797,0	20230,6	19686,6	22426,2	23325,2	26913,0	20275,4
Nd-143	11437,0	13165,3	13339,6	12374,9	12718,9	12918,0	14565,0	10766,2
Nd-144	20244,0	26188,9	28953,4	28735,1	34008,0	35658,6	41457,8	31423,9
Nd-145	10356,3	12663,4	13452,9	12962,3	14473,2	14987,4	17220,4	12929,4
Nd-146	10047,6	12851,2	14098,2	13914,0	16293,4	17046,5	19777,9	14966,4
Sm-152	1387,2	1693,3	1796,6	1729,4	1927,2	1994,7	2291,0	1719,5
Eu-153	1587,3	2063,6	2288,9	2277,0	2706,7	2840,6	3305,4	2507,1
Gd-156	1179,4	1872,3	2328,3	2494,4	3361,7	3613,7	4297,9	3315,9
Np-237	3731,1	4905,2	5508,9	5384,7	6257,0	6517,3	7550,7	5692,5
Pu-239	55493,1	63704,0	64132,0	59172,0	59597,6	60036,1	67307,0	49431,5
Pu-240	27328,3	34559,4	37356,9	36094,9	40832,6	42253,2	48857,4	36270,7
Pu-241	8114,8	10590,8	11623,9	11272,3	12610,1	12995,1	14776,8	10982,0
Pu-242	4322,3	6688,9	8257,0	8949,8	12384,9	13451,1	16058,0	12405,1
Am-241	3346,3	4236,3	4537,3	4319,6	4593,7	4681,3	5295,7	3941,9
Am-243	474,1	812,2	1074,2	1242,6	1981,6	2279,9	2801,6	2241,7
Cm-244	55,8	135,4	200,4	254,4	483,4	562,4	734,6	613,3
TOTAL U *	1,340E+07	1,522E+07	1,525E+07	1,401E+07	1,408E+07	1,422E+07	1,594E+07	1,173E+07

ELEMENTS

	MOLES/SPECIMEN							
SPECIMEN	**11-1**	**11-2**	**11-3**	**11-4**	**11-5**	**11-6**	**11-7**	**11-8**
Wt.U Init (g)	13,943	15,926	16,033	14,793	15,012	15,199	17,083	12,594
U	5,63E-02	6,39E-02	6,41E-02	5,89E-02	5,92E-02	5,97E-02	6,70E-02	4,93E-02
Np	1,57E-05	2,07E-05	2,32E-05	2,27E-05	2,64E-05	2,75E-05	3,19E-05	2,40E-05
Pu	3,98E-04	4,82E-04	5,07E-04	4,82E-04	5,24E-04	5,38E-04	6,14E-04	4,55E-04
Cm	2,29E-07	5,55E-07	8,21E-07	1,04E-06	1,98E-06	2,30E-06	3,01E-06	2,51E-06
La	9,89E-05	1,23E-04	1,33E-04	1,29E-04	1,48E-04	1,54E-04	1,78E-04	1,34E-04
Ce	1,89E-04	2,35E-04	2,54E-04	2,47E-04	2,83E-04	2,94E-04	3,40E-04	2,56E-04
Pr	1,07E-04	1,33E-04	1,43E-04	1,40E-04	1,59E-04	1,65E-04	1,91E-04	1,44E-04
Nd	4,20E-04	5,26E-04	5,68E-04	5,54E-04	6,34E-04	6,60E-04	7,63E-04	5,75E-04
Eu	1,24E-05	1,61E-05	1,79E-05	1,78E-05	2,12E-05	2,22E-05	2,59E-05	1,96E-05

Table D 4. (Continued) Series 11 Corrosion tests
Specimen inventories (ICP-MS) of selected nuclides and elements

NUCLIDES

	MICROGRAMS/SPECIMEN							
Wt.U Init (g)	15,380	15,268	15,318	15,583	15,630	15,549	16,077	15,659
B.U.	44,9	45,8	46,5	47,0	47,6	48,1	48,4	48,8
NUCL	11-9	11-10	11-11	11-12	11-13	11-14	11-15	11-16
Rb-85	2019,8	2032,0	2059,6	2110,5	2135,2	2139,3	2221,4	2175,9
Rb-87	4430,1	4455,4	4515,0	4625,7	4679,0	4687,3	4866,7	4766,4
Sr-88	5892,0	5928,7	6010,1	6159,2	6232,1	6244,8	6484,8	6352,4
Sr-90	7728,6	7770,6	7872,7	8064,6	8155,9	8169,2	8481,1	8305,4
Y-89	8097,3	8148,8	8261,7	8467,2	8568,2	8586,2	8916,6	8735,1
Zr-93	12955,4	13068,1	13272,5	13619,6	13802,0	13847,7	14390,6	14110,8
Mo-95	13763,1	13880,4	14095,5	14462,7	14654,7	14701,8	15277,4	14979,3
Mo-97	15177,3	15334,5	15593,7	16015,2	16246,3	16313,6	16961,5	16642,6
Mo-98	15776,0	15944,9	16218,6	16660,1	16904,0	16976,9	17653,0	17323,4
Mo-100	18132,1	18334,6	18655,6	19168,1	19454,2	19542,6	20323,6	19947,7
Tc-99	14291,2	14414,2	14638,6	15020,6	15220,9	15270,5	15868,7	15559,6
Ru-101	14942,4	15105,8	15367,6	15787,8	16021,2	16092,2	16734,2	16423,1
Rh-103	7335,6	7369,3	7461,4	7639,8	7722,3	7731,5	8024,6	7855,7
Cs-133	20693,3	20827,6	21118,2	21645,1	21904,8	21952,5	22798,0	22335,1
Cs-135	7170,3	7147,9	7194,6	7335,9	7378,4	7357,0	7617,3	7432,9
Cs-137	19585,0	19799,7	20143,4	20694,5	21000,8	21094,1	21935,8	21528,4
Ba-138	24984,1	25243,6	25670,7	26365,1	26745,9	26857,0	27923,9	27399,1
La-139	23201,1	23433,1	23822,7	24462,1	24809,6	24907,8	25894,4	25403,9
Ce-140	23499,2	23744,6	24147,4	24801,3	25160,4	25265,7	26269,8	25776,7
Pr-141	25291,2	25538,0	25957,9	26651,3	27025,8	27129,6	28202,1	27665,3
Nd-143	13182,7	13115,0	13180,0	13424,1	13483,9	13430,0	13896,0	13547,6
Nd-144	39426,0	39992,2	40789,0	41978,5	42687,5	42949,0	44706,9	43933,5
Nd-145	16075,4	16190,6	16424,8	16840,5	17049,8	17092,8	17754,7	17398,9
Nd-146	18748,3	18994,4	19355,1	19906,9	20228,1	20339,7	21164,7	20788,8
Sm-152	2137,2	2151,9	2182,6	2237,6	2265,0	2270,4	2358,1	2310,6
Eu-153	3147,6	3194,3	3259,2	3355,1	3412,8	3434,6	3575,7	3514,5
Gd-156	4229,3	4344,7	4473,0	4633,2	4747,0	4805,1	5019,5	4955,7
Np-237	7136,3	7194,3	7303,6	7479,8	7589,9	7606,6	7897,0	7735,5
Pu-239	60289,6	59697,9	59587,0	60462,0	60488,1	60019,1	61976,8	60287,2
Pu-240	45063,4	45269,6	45954,0	47138,6	47515,2	47579,9	49356,4	48229,7
Pu-241	13534,4	13512,2	13633,0	13915,6	13988,9	13947,5	14437,1	14077,4
Pu-242	15918,3	16413,1	17003,0	17686,7	18209,0	18425,6	19292,4	19104,0
Am-241	4844,7	4824,7	4840,5	4939,8	4954,7	4944,6	5112,5	4979,6
Am-243	2968,3	3129,9	3278,1	3428,3	3579,3	3700,7	3906,7	3883,4
Cm-244	849,0	939,0	1026,3	1106,4	1187,9	1243,9	1326,4	1370,2
TOTAL U *	1,429E+07	1,416E+07	1,419E+07	1,442E+07	1,445E+07	1,436E+07	1,484E+07	1,444E+07

ELEMENTS

	MOLES/SPECIMEN							
SPECIMEN	11-9	11-10	11-11	11-12	11-13	11-14	11-15	11-16
Wt.U Init (g)	15,380	15,268	15,318	15,583	15,630	15,549	16,077	15,659
U	6,00E-02	5,95E-02	5,96E-02	6,06E-02	6,07E-02	6,03E-02	6,23E-02	6,07E-02
Np	3,01E-05	3,04E-05	3,08E-05	3,16E-05	3,20E-05	3,21E-05	3,33E-05	3,26E-05
Pu	5,63E-04	5,63E-04	5,69E-04	5,81E-04	5,85E-04	5,84E-04	6,06E-04	5,92E-04
Cm	3,48E-06	3,85E-06	4,21E-06	4,53E-06	4,87E-06	5,10E-06	5,44E-06	5,62E-06
La	1,67E-04	1,69E-04	1,71E-04	1,76E-04	1,78E-04	1,79E-04	1,86E-04	1,83E-04
Ce	3,20E-04	3,23E-04	3,28E-04	3,37E-04	3,42E-04	3,43E-04	3,57E-04	3,50E-04
Pr	1,79E-04	1,81E-04	1,84E-04	1,89E-04	1,92E-04	1,92E-04	2,00E-04	1,96E-04
Nd	7,18E-04	7,25E-04	7,38E-04	7,57E-04	7,68E-04	7,72E-04	8,02E-04	7,87E-04
Eu	2,46E-05	2,50E-05	2,55E-05	2,62E-05	2,67E-05	2,69E-05	2,80E-05	2,75E-05

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Kemakta Konsult AB
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Roy Stanfors[1], Mikael Erlström[2], Ingemar Markström[3]
[1] RS Consulting, Lund
[2] SGU, Lund
[3] Sydkraft Konsult, Malmö
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Ingvar Rhén (ed.)[1], Göran Bäckblom (ed.)[2], Gunnar Gustafson[3], Roy Stanfors[4], Peter Wikberg[2]
[1] VBB Viak, Göteborg
[2] SKB, Stockholm
[3] VBB Viak/CTH, Göteborg
[4] RS Consulting, Lund
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Roy Stanfors[1], Pär Olsson[2], Håkan Stille[3]
[1] RS Consulting, Lund
[2] Skanska, Stockholm
[3] KTH, Stockholm
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Ingvar Rhén[1], Gunnar Gustafson[2], Peter Wikberg[3]
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[2] VBB Viak/CTH, Göteborg
[3] SKB, Stockholm
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[1] Dept. of Chemical Engineering, UPC
[2] QuantiSci SL
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AECL, Whiteshell Laboratories, Pinawa, Manitoba, Canada
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Department of Chemical Engineering and Technology, Chemical Engineering, Royal Institute of Technology, Stockholm, Sweden
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[1] Kemakta Konsult AB, Sweden
[2] AEA Technology, UK
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Göteborg University, Institute of Cell and Molecular Biology, Dept. of General and Marine Microbiology, Göteborg, Sweden
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[1] INTERA KB
[2] VBB Viak
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Saanio & Riekkola Oy, Helsinki, Finland
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