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SIMULATED HLLW COMPOSITIONS FOR COLD TEST OF WASTE MANAGEMENT DEVELOPMENT

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Division of Environmental Safety Research,
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(Received June 29, 1982)

Three grades of simulated high-level liquid waste(HLLW) - JW-A, JW-B, and JW-C - were proposed to be used respectively according to stages of various cold tests for safety assessment of HLW management.

The composition of HLLW was estimated taking into account the spectrum of fission products and actinides, waste volume, corrosion products, and chemical additives. One of conditions, the spectrum of fission products and actinides of LWR spent fuels, was calculated by DCHAIN-code. Fuel burn-up of 28,000 MWD/tUO_2 and 33,000 MWD/tUO_2 were adopted as nomal and maximum values of Japanese LWR power plants. The other conditions were estimated using the data obtained at Marcoule plant in France.

Keywords; High-level Radioactive Waste, DCHAIN-Code, Fission Products, Actinides, Simulated Waste, Corrosion Products, Rare-earth Elements, Burn-up, Radioactive Waste Disposal

コールド試験用模擬高レベル廃液組成

日本原子力研究所東海研究所環境安全研究部
馬場　恒孝・木村　英雄・上薗　裕史・田代　晋吾

（1982年6月29日受理）

高レベル放射性廃棄物処理処分技術の研究開発を行うに際して必要である各種コールド試験に応じ，模擬廃液組成として3種類の廃液，JW－A，JW－BおよびJW－Cを決めた。

高レベル廃液の組成は，使用済核燃料中に含まれる核分裂生成物（FP）とアクチノイド元素の含有量，廃液発生量，腐食生成物量および再処理工程で混入する化学物質の量等を考慮して推定された。核分裂生成物およびアクチノイド元素の生成量の計算は，日本の発電用軽水炉の一般的な燃焼率，28,000 MWD／t・UO_2および33,000 MWD／t・UO_2について，DCHAINコードを使用して行った。

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1. INTRODUCTION

High-level radioactive liquid wastes(HLLW) from reprocessing of LWR(Light Water Reactor) spent fuel consist of fission product elements, actinide elements, corrosion products and chemical additives used in the reprocessing plant. On developing the techniques of HLLW management, cold test prior to experiments using real waste is imperative for safety in the experiments and efficiency of hot test.

In 1974, W.K. Winegardner, et al.[1] estimated the composition of HLLW on the basis of the computed data using ORIGEN-code, which was developed in Oak Ridge National Laboratory(ORNL)[2]. The same study was carried out independently by H. Krause in Nuclear Research Center Karlsruhe in 1974[3]. Thereafter, based on their estimations many researchers proposed the composition of the simulated HLLW[4]. However, there are very few reports which give a sufficient consideration about physical and chemical grounds for the simulation.

In this report, the composition of HLLW from reprocessing of the typical LWR spent fuel in Japan are studied from the point of view of simulating the HLLW composition. The spectra of fission products and actinides from LWR spent fuel are calculated using DCHAIN-code, which was developed in the Japan Atomic Energy Research Institute(JAERI)[5]. The composition of HLLW is estimated on the basis of these computed data and the data about corrosion products and chemical additives, which have already been reported for the typical reprocessing waste. To adapt the grade of simulation to the purpose of the test is economically efficient with consistency in its chemical and physical properties. After discussing the basic aspects of simulation, three types of simulated HLLW are proposed for various stages of safety evaluation tests, which have been planned in JAERI.

2. COMPUTER CODE

"DCHAIN" is used for the calculation in the present work. "DCHAIN" has been developed as a one-point depletion code which solves the coupled equations of radioactive growth and decay for a large number of nuclides by Bateman method. The Bateman method surpasses the matrix exponential method, which is used in ORIGEN-code, in computational variety for burning condition and saving core memory. "DCHAIN" is a computer code which has surmounted such the disadvantage that proven codes using the Bateman method could not deal with the cyclic chains and some special types of decay chains[5]. Also we have the following advantages in use of DCHAIN-code. A library of nuclear data which exerts a large influence in computational accuracies of fission products and actinides will be revised up to date by a maintenance group of DCHAIN-code in JAERI according to the progress of nuclear data. A library of nuclear data for DCHAIN-code has been already revised using various nuclear data pablished up to 1980.

In order to obtain convenient out put lists of composition of high-level wastes, the DCHAIN-code was modified as follows.
(1) To take into account recovery and release conditions of several elements in the reprocessing on accumulation of each nuclide of fission products and actinides.
(2) To print out the results in gram-atom and gram other than the number of atoms.
(3) To print out the sum of each element.

3. INPUT DATA FOR CALCULATION

Input data were selected as follows from a general reactor which is operated now in Japan[6]. Various values of losses of elements in storage tank of HLLW will depend upon reprocessing condition and storage period. These values were dicided based on literature survey.

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(1) Type of reactor

Light water reactor (LWR)

(2) Enrichment factor of uranium-235

2.41 %

(3) Thermal neutron flux under 0.5 eV and total neutron flux

2.23×10^{13} n/cm^{2}sec (Thermal neutron flux)

3.20×10^{14} n/cm^{2}sec (Total neutron flux)

(4) Reactor power per a metric ton of a typical UO_2 fuel

35 MW/t

(5) Average burn-up

28,000 MWD/tUO_2, 33,000 MWD/tUO_2

(6) Cooling time prior to reprocessing

180 days

(7) Residue of each element in the high-level waste at reprocessing process

Br = Kr = Xe = 0 %

I = 10 %

U = 0.1 %, Pu = 0.3 %

Others = 100 %

(8) Years after reprocessing at which the computed results are printed out

1, 3, 5, 10, 20, 50, 100, 1000, 10000 years

4. COMPUTED RESULTS

The compositions for the raffinates from the Purex reprocessing of light water reactor fuels irradiated to 28,000 MWD/tUO_2 and 33,000 MWD/tUO_2 are calculated under the above conditions. Table 1 - Table 4 and Table 5 - Table 8 list the computed results based on a burn-up at 28,000 MWD/tUO_2 and 33,000 MWD/tUO_2, respectively. The fission product contents in raffinate are shown in Table 1, Table 5(in the number of atoms) and Table 2, Table 6(in gram-atom). The actinides - thorium, uranium, neptunium, plutonium, americium, and curium - and lead contents in faffinate

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5. CONSTITUTION OF HIGH-LEVEL LIQUID WASTE

Composition of HLLW is estimated on the basis of the composition of the raffinate from the reprocessing. The HLLW volume per a metric ton of UO_2 fuel, the addition of chemicals in the reprocessing plant, the corrosion products arising from the corrosion of the reprocessing plant etc. will depend on the variety in the design and operation.

The bases for the amounts of constituents in the waste compositions are discussed below.

Fission Products and Actinides

The amounts of fission products and actinides in HLLW are estimated from the computed results of five years after reprocessing shown in the preceding chapter.

Waste Volume

An experience of the Power Reactor and Nuclear Fuel Development Corporation(PNC) reprocessing plant has shown that the HLLW volume of about 1 m^3/tU has been generated from the plant[7]. However, this result is based on the operation to the treatment of a little under 20 ton spent fuels from the start-up. In the WSEP program at BNWL, the volume of HLLW has been assumed of 378 ℓ/tHM (100 gal/tHM)[8][9]. In France the HLLW volume is assumed of 500 ℓ/tHM[4]. Therefore, it is are shown in Table 3, Table 7(in the number of atoms) and Table 4, Table 8(in gram-atom). Fission products with the number of atoms less than 10^{14} are omitted. Contents of multineutron capture products, such as ^{241}Am, ^{244}Cm, ^{134}Cs are affected by burn-up as shown in Fig.1.

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Acid Concentration

No neutralized wastes are anticipated in commercial plants. A raffinate concentration of 500 ℓ/t containing 1.5 - 2.0 mol/ℓ nitric acid is assumed at Marcoule in France and PNC in Japan[7][4]. In this report 2.0 mol/ℓ-HLLW is used as the concentration of nitric acid as the same reason mentioned above.

Sodium

Sodium comes from additives auch as $NaNO_2$ for plutonium valence control. If washing solution of solvent recovery, off-gas scrubbing solution and other waste solution are combined with HLLW, the content of sodium will extremely increase. The concentration of sodium is assumed 1 mol/ℓ-HLLW at PNC[7]. In France, the value between 0.226 mol/ℓ-HLLW and 0.968 mol/ℓ-HLLW as a sodium concentration is supposed[4]. In this report, 0.597 mol/ℓ-HLLW which is a medium value of above estimations, is used.

Corrosion Products

Iron comes from corrosion in plant liners plus dissolusion of springs in some LWR fuel elements. Chromium and nickel come only from corrosion of stainless-steel equipments. These quantities will change dependently on the operation conditions. In this report, with reference to the data of France[4], 0.194 mol/ℓ-HLLW, 0.0296 mol/ℓ-HLLW and 0.0261 mol/ℓ-HLLW are used as the concentration of iron, chromium and nickel, respectively.

Phosphate

The phosphate comes from degradation products of the TBP(

Tri-n-butyl Phosphate) solvent and its colloidal dispersion in HLLW. The value used (0.0263 mol/ℓ-HLLW) is the value reported in France[4].

The results decided based on above reason are shown in Table 9. In this table, a content of each element more than 10^{-4} gram-atom is shown in gram-atom per one liter of HLLW.

6. PRINCIPLE OF SIMULATION

In this section, basic aspects of the simulation of elements in HLLW are described.

The first principle of simulation is that an element should be replaced by other element which belongs to the same group in the periodic table because they may have similar physical and chemical properties.

On the studies of the vitrification of HLLW, it is also important to consider the roles of each element in glass structures; network formers, intermediates and modifiers. The role of element depends on valence, coordination number and the related value of single-bond strength. Thus the second principle on simulation is that an element included in the network former can not be replaced by other elements having a role of network modifier.

The addition of modifier elements to SiO_2 increases the ratio of oxygen to silicon(O/Si) to a value greater than 2 and break up the three-dimensional network with the formation of singly bonded oxygens which do not participate in the network[10]. The ratio of O/Si in glass is important parameter on a physical property, such that the increment of the ratio of O/Si increases the thermal expansion coefficient of the glass[11]. Thus the third principle of simulation is that the ratio of O/Si is not changed to maintain its physical property.

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On the other hand, C.R. Das has discussed the relation between the rate of extraction of SiO_2 and Na_2O in a glass and the field strength of the other cations showing that the rate of extraction of SiO_2 and Na_2O was governed by the extent of field strength of other cations[12]. Field strength is represented as Z/r^2, where Z is a atomic valence and r is a ion radius. Elements which have similar atomic valences and similar ion radii have also similar values of field strength. The fourth principle of simulation is that similar atomic valences and ion radii could be replaced by each other.

All of the simulation rules outlined above can not be fulfilled in practice, therefore priority of the principles of simulation may be changed according to objectives of an experiment. Especially on the study of physical and chemical properties depended on devitrification, it is necessary to take care of simulation of the noble metal elements, which are connected with the devitrification of waste glass.

7. COMPOSITION OF SIMULATED HIGH-LEVEL LIQUID WASTE

Three kinds of simulated HLLW(JW-A, JW-B, JW-C) shown in Table 10 were decided in consideration of both the purpose of tests and economical efficiency.

JW-A is the highest simulation of HLLW for a leaching test, a volatility test, a radiation durability test, a thermal stability test of waste products, etc. Because it is necessary to investigate the effects of a trace element in these tests. In JW-A waste, technetium and promethium are replaced by manganese and neodymium, respectively. Actinides- uranium, neptunium, plutonium, americium and curium- are also replaced by cerium. Cerium also belongs to the same group in the periodic table as actinides and the electron configulation, the ion radius and the structure of oxide are also similar to these of uranium which is present in large quantities compared to other actinide elements[13].

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JW-B is for investigations of physical properties of waste products, such as a thermal conductivity, a thermal expansion, etc. In JW-B waste, small constituents such as selenium, tin, and antimony are omitted. The actinides and the rare-earths - yttrium, lanthanium,cerium, praseodymium, neodymium, promethium, samarium, europium and gadolinium- are replaced by the mixed rare-earth nitrates with the approximate composition (weight percent) of La_2O_3(9.95), Ce_2O_3(32.1), Pr_6O_{11}(4.8), Nd_2O_3(20.7), Sm_2O_3(8.8), Gd_2O_3(8.1), Tb_2O_3(1.2), Dy_2O_3(4.3), Er_2O_3(0.9) and Y_2O_3(8.1). Technetium is also replaced by manganese and the noble metals such as ruthenium, rhodium and palladium are replaced by iron, cobalt and nickel, respectively, for economical reasons. Iron, cobalt and nickel belong to the same group in the periodic table as ruthenium, rhodium and palladium, respectively.

JW-C is for the tests on the strength of waste products, such as a drop impact test and a thermal shock test, and developments of waste solidification process. In JW-C waste, the elements with concentrations less than 0.0015 gram-atom/ℓ-HLLW i.e. selenium, silver, cadmium, tin and antimony are omitted. Rubidium is replaced by potassium that belongs to alkaline metals group and then technitium, ruthenium, rhodium and palladium are also replaced by manganese, iron, cobalt and nickel, respectively. The actinides and the rare-earths are replaced by calcium that belongs to II-A group in the periodic table. This replacement has already been reported by H. Krause [3].

In principle, the nitrates are selected for the compounds used to prepare simulated waste solutions on the assumption that all elements could be dissolved in the solution. When the nitrates of some elements cannot come to hand, the compounds are selected for preparation of simulated wastes in consideration of their solubility in nitric acid solution. Table 11 lists the compounds used to prepare three simulated HLLW and the molar concentration of the compounds.

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Table 1 Composition of FP in HLW from reprocessing fuels with burnup 28,000 MWD/t·UO_2 (the number of atoms/t)

Element \ Time (y)	1	3	5	10	20	50	100	1000	10000
NI	0.26758E+19	0.25238E+19	0.23850E+19	0.20883E+19	0.16632E+19	0.11120E+19	0.94135E+18	0.92159E+18	0.92159E+18
ZN	0.53170E+19	0.53170E+19	0.53170E+19	0.53170E+19	0.53170E+19	0.53170E+19	0.53170E+19	0.53170E+19	0.53170E+19
GA	0.10994E+20	0.11146E+20	0.11285E+20	0.11582E+20	0.12007E+20	0.12558E+20	0.12728E+20	0.12748E+20	0.12748E+20
GE	0.27006E+22	0.27006E+22	0.27006E+22	0.27006E+22	0.27006E+22	0.27006E+22	0.27006E+22	0.27006E+22	0.27006E+22
AS	0.85709E+21	0.85709E+21	0.85709E+21	0.85709E+21	0.85709E+21	0.85709E+21	0.85709E+21	0.85709E+21	0.85709E+21
SE	0.27006E+24	0.27006E+24	0.27006E+24	0.27006E+24	0.27006E+24	0.27005E+24	0.27003E+24	0.26974E+24	0.26695E+24
BR	0.32825E+18	0.98474E+18	0.16412E+19	0.32824E+19	0.65644E+19	0.16408E+20	0.32808E+20	0.32651E+21	0.31136E+22
KR	0.19395E+18	0.20359E+18	0.20361E+18	0.20361E+18	0.20361E+18	0.20361E+18	0.20361E+18	0.20361E+18	0.20361E+18
RB	0.20060E+25	0.19679E+25	0.19309E+25	0.18426E+25	0.16835E+25	0.13195E+25	0.96658E+24	0.61363E+24	0.61363E+24
SR	0.50659E+25	0.49517E+25	0.48624E+25	0.46369E+25	0.42710E+25	0.36412E+25	0.33352E+25	0.34037E+25	0.34037E+25
Y	0.26291E+25	0.26287E+25	0.26287E+25	0.26285E+25	0.26285E+25	0.26282E+25	0.26281E+25	0.26280E+25	0.26280E+25
ZR	0.19514E+26	0.19656E+26	0.19793E+26	0.20105E+26	0.20632E+26	0.21626E+26	0.22285E+26	0.22566E+26	0.22541E+26
NB	0.20951E+22	0.24951E+21	0.25443E+21	0.26879E+21	0.29751E+21	0.38368E+21	0.52728E+21	0.31116E+22	0.28873E+23
MO	0.17886E+26	0.17889E+26	0.17889E+26	0.17889E+26	0.17889E+26	0.17889E+26	0.17889E+26	0.17889E+26	0.17889E+26
TC	0.44341E+25	0.44341E+25	0.44340E+25	0.44340E+25	0.44338E+25	0.44334E+25	0.44327E+25	0.44197E+25	0.42921E+25
RU	0.11117E+26	0.10906E+26	0.10852E+26	0.10835E+26	0.10835E+26	0.10835E+26	0.10836E+26	0.10849E+26	0.10976E+26
RH	0.24861E+25	0.24861E+25	0.24861E+25	0.24861E+25	0.24861E+25	0.24861E+25	0.24861E+25	0.24861E+25	0.24861E+25
PD	0.60741E+25	0.62857E+25	0.63392E+25	0.63568E+25	0.63573E+25	0.63573E+25	0.63573E+25	0.63572E+25	0.63563E+25
AG	0.38873E+24	0.38822E+24	0.38815E+24	0.38814E+24	0.38814E+24	0.38814E+24	0.38815E+24	0.38824E+24	0.38914E+24
CD	0.34193E+24	0.34246E+24	0.34253E+24	0.34253E+24	0.34252E+24	0.34251E+24	0.34251E+24	0.34251E+24	0.34251E+24
IN	0.82213E+22	0.82249E+22	0.82281E+22	0.82347E+22	0.82440E+22	0.82548E+22	0.82576E+22	0.82578E+22	0.82578E+22
SN	0.18954E+24	0.18932E+24	0.18927E+24	0.18915E+24	0.18894E+24	0.18839E+24	0.18775E+24	0.18631E+24	0.18271E+24
SB	0.65559E+23	0.56570E+23	0.51081E+23	0.45175E+23	0.43221E+23	0.43565E+23	0.44183E+23	0.45252E+23	0.45252E+23
TE	0.20904E+25	0.20993E+25	0.21049E+25	0.21109E+25	0.21130E+25	0.21132E+25	0.21133E+25	0.21136E+25	0.21172E+25
I	0.10987E+24	0.11021E+24	0.11021E+24	0.11021E+24	0.11021E+24	0.11021E+24	0.11021E+24	0.11021E+24	0.11017E+24
XE	0.42122E+16	0.11263E+17	0.18314E+17	0.35942E+17	0.71197E+17	0.17696E+18	0.35324E+18	0.35261E+19	0.35249E+20
CS	0.10969E+26	0.10645E+26	0.10391E+26	0.98962E+25	0.91395E+25	0.77021E+25	0.67120E+25	0.62513E+25	0.62465E+25
BA	0.53734E+25	0.56910E+25	0.59512E+25	0.64463E+25	0.72029E+25	0.86404E+25	0.96304E+25	0.10091E+26	0.10096E+26
LA	0.46320E+25	0.46320E+25	0.46320E+25	0.46320E+25	0.46320E+25	0.46320E+25	0.46320E+25	0.46320E+25	0.46320E+25
CE	0.91057E+25	0.87579E+25	0.86992E+25	0.86874E+25	0.86873E+25	0.86873E+25	0.86873E+25	0.86873E+25	0.86873E+25
PR	0.43175E+25	0.43175E+25	0.43175E+25	0.43175E+25	0.43175E+25	0.43175E+25	0.43175E+25	0.43175E+25	0.43175E+25
ND	0.13960E+26	0.14307E+26	0.14366E+26	0.14378E+26	0.14378E+26	0.14378E+26	0.14378E+26	0.14378E+26	0.14378E+26
PM	0.53764E+24	0.31693E+24	0.18682E+24	0.49843E+23	0.35477E+22	0.12806E+19			
SM	0.24736E+25	0.26931E+25	0.28233E+25	0.29590E+25	0.30028E+25	0.30000E+25	0.29921E+25	0.29746E+25	0.29746E+25
EU	0.54337E+24	0.51969E+24	0.50051E+24	0.46758E+24	0.43732E+24	0.42506E+24	0.43175E+24	0.44923E+24	0.44925E+24
GD	0.22914E+24	0.25345E+24	0.27308E+24	0.30731E+24	0.34003E+24	0.35866E+24	0.35988E+24	0.35992E+24	0.35996E+24
TB	0.83524E+22	0.83510E+22	0.83508E+22	0.83506E+22	0.83500E+22	0.83484E+22	0.83459E+22	0.83192E+22	0.82752E+22
DY	0.41176E+22	0.41170E+22	0.41190E+22	0.41191E+22	0.41192E+22	0.41194E+22	0.41198E+22	0.41251E+22	0.41339E+22
HO	0.50783E+20	0.50767E+20	0.50750E+20	0.50709E+20	0.50628E+20	0.50386E+20	0.49993E+20	0.44638E+20	0.37319E+20
ER	0.33705E+20	0.33716E+20	0.33727E+20	0.33755E+20	0.33812E+20	0.33978E+20	0.34249E+20	0.37997E+20	0.43463E+20

Time represents cooling time after reprocessing

Table 2 Composition of FP in HLW from reprocessing fuels with burnup 28,000 MWD/t·UO_2 (g-atom/t)

Element \ Time (y)	1	3	5	10	20	50	100	1000	10000
NI	0.44426E-05	0.41903E-05	0.39598E-05	0.34672E-05	0.27614E-05	0.19463E-05	0.15629E-05	0.15301E-05	0.15301E-05
ZN	0.88279E-05	0.88279E-05	0.88279E-05	0.88279E-05	0.88279E-05	0.88279E-05	0.88279E-05	0.88279E-05	0.88279E-05
GA	0.18254E-04	0.18506E-04	0.18736E-04	0.19229E-04	0.19935E-04	0.20850E-04	0.21133E-04	0.21166E-04	0.21166E-04
GE	0.44839E-02	0.44839E-02	0.44839E-02	0.44839E-02	0.44839E-02	0.44839E-02	0.44839E-02	0.44839E-02	0.44839E-02
AS	0.14230E-02	0.14230E-02	0.14230E-02	0.14230E-02	0.14230E-02	0.14230E-02	0.14230E-02	0.14230E-02	0.14230E-02
SE	0.44839E+00	0.44839E+00	0.44838E+00	0.44838E+00	0.44838E+00	0.44836E+00	0.44833E+00	0.44784E+00	0.44322E+00
BR	0.34499E-06	0.16350E-05	0.27249E-05	0.54498E-05	0.10899E-04	0.27242E-04	0.54471E-04	0.54211E-03	0.51695E-02
KR	0.32201E-06	0.33802E-06	0.33806E-06	0.33806E-06	0.33806E-06	0.33806E-06	0.33806E-06	0.33806E-06	0.33806E-06
RB	0.33306E+01	0.32674E+01	0.32059E+01	0.30593E+01	0.27952E+01	0.21908E+01	0.16048E+01	0.10188E+01	0.10188E+01
SR	0.84126E+01	0.82380E+01	0.80720E+01	0.76986E+01	0.70911E+01	0.60455E+01	0.55374E+01	0.56512E+01	0.56512E+01
Y	0.43652E+01	0.43645E+01	0.43644E+01	0.43643E+01	0.43641E+01	0.43637E+01	0.43634E+01	0.43633E+01	0.43633E+01
ZR	0.32399E+02	0.32635E+02	0.32862E+02	0.33383E+02	0.34255E+02	0.35905E+02	0.36999E+02	0.37467E+02	0.37424E+02
NB	0.34784E-02	0.41426E-03	0.42243E-03	0.44627E-03	0.49396E-03	0.63702E-03	0.87545E-03	0.51662E-02	0.47938E-01
MO	0.29696E+02	0.29702E+02	0.29702E+02	0.29702E+02	0.29702E+02	0.29702E+02	0.29702E+02	0.29702E+02	0.29702E+02
TC	0.73619E+01	0.73619E+01	0.73618E+01	0.73610E+01	0.73614E+01	0.73608E+01	0.73596E+01	0.73380E+01	0.71262E+01
RU	0.18458E+02	0.18107E+02	0.18018E+02	0.17989E+02	0.17989E+02	0.17949E+02	0.17991E+02	0.18012E+02	0.18224E+02
RH	0.41277E+01	0.41277E+01	0.41277E+01	0.41277E+01	0.41277E+01	0.41277E+01	0.41277E+01	0.41277E+01	0.41277E+01
PD	0.10085E+02	0.10436E+02	0.10523E+02	0.10554E+02	0.10555E+02	0.10555E+02	0.10555E+02	0.10555E+02	0.10553E+02
AG	0.64544E+00	0.64456E+00	0.64444E+00	0.64442E+00	0.64443E+00	0.64443E+00	0.64444E+00	0.64459E+00	0.64608E+00
CD	0.56771E+00	0.56858E+00	0.56870E+00	0.56870E+00	0.56869E+00	0.56867E+00	0.56866E+00	0.56866E+00	0.56866E+00
IN	0.13650E-01	0.13656E-01	0.13661E-01	0.13672E-01	0.13687E-01	0.13705E-01	0.13710E-01	0.13710E-01	0.13710E-01
SN	0.31469E+00	0.31433E+00	0.31424E+00	0.31405E+00	0.31369E+00	0.31279E+00	0.31173E+00	0.30934E+00	0.30336E+00
SB	0.10885E+00	0.93923E-01	0.84810E-01	0.75004E-01	0.71759E-01	0.72331E-01	0.73357E-01	0.75132E-01	0.75132E-01
TE	0.34708E+01	0.34835E+01	0.34947E+01	0.35047E+01	0.35083E+01	0.35086E+01	0.35087E+01	0.35093E+01	0.35153E+01
I	0.18241E+00	0.18297E+00	0.18298E+00	0.18298E+00	0.18298E+00	0.18298E+00	0.18298E+00	0.18297E+00	0.18292E+00
XE	0.69935E-08	0.18700E-07	0.30407E-07	0.59674E-07	0.11821E-06	0.29360E-06	0.58648E-06	0.58544E-05	0.58523E-04
CS	0.18212E+02	0.17675E+02	0.17253E+02	0.16431E+02	0.15174E+02	0.12788E+02	0.11144E+02	0.10379E+02	0.10371E+02
BA	0.89214E+01	0.94587E+01	0.98809E+01	0.10703E+02	0.11959E+02	0.14346E+02	0.15989E+02	0.16755E+02	0.16762E+02
LA	0.76905E+01	0.76905E+01	0.76905E+01	0.76905E+01	0.76905E+01	0.76905E+01	0.76905E+01	0.76905E+01	0.76905E+01
CE	0.15118E+02	0.14541E+02	0.14443E+02	0.14424E+02	0.14424E+02	0.14424E+02	0.14424E+02	0.14424E+02	0.14424E+02
PR	0.71684E+01	0.71684E+01	0.71684E+01	0.71684E+01	0.71684E+01	0.71684E+01	0.71684E+01	0.71684E+01	0.71684E+01
ND	0.23177E+02	0.23755E+02	0.23852E+02	0.23872E+02	0.23872E+02	0.23872E+02	0.23872E+02	0.23872E+02	0.23872E+02
PM	0.89265E+00	0.52620E+00	0.31018E+00	0.82755E-01	0.58903E-02	0.21261E-05			
SM	0.41069E+01	0.44724E+01	0.46876E+01	0.49128E+01	0.49856E+01	0.49810E+01	0.49678E+01	0.49388E+01	0.49387E+01
EU	0.90216E+00	0.86269E+00	0.83100E+00	0.77632E+00	0.72608E+00	0.70573E+00	0.71684E+00	0.74586E+00	0.74590E+00
GD	0.38045E+00	0.42081E+00	0.45339E+00	0.51023E+00	0.56456E+00	0.57549E+00	0.59751E+00	0.59758E+00	0.59764E+00
TB	0.13868E-01	0.13865E-01	0.13865E-01	0.13864E-01	0.13864E-01	0.13861E-01	0.13857E-01	0.13812E-01	0.13739E-01
DY	0.68365E-02	0.68388E-02	0.68388E-02	0.68389E-02	0.68390E-02	0.68394E-02	0.68400E-02	0.68488E-02	0.68636E-02
HO	0.84315E-04	0.84288E-04	0.84261E-04	0.84193E-04	0.84057E-04	0.83656E-04	0.83003E-04	0.74112E-04	0.61961E-04
ER	0.55961E-04	0.55979E-04	0.55998E-04	0.56044E-04	0.56139E-04	0.56414E-04	0.56864E-04	0.63087E-04	0.72162E-04

Time represents cooling time after reprocessing

Table 3 Composition of actinides in HLW from reprocessing fuels with burnup 28,000 MWD/t·UO_2
(the number of atoms/t)

Time (y) / Element	1	3	5	10	20	50	100	1000	10000
PB	0.20541+16	0.35538+16	0.43229+16	0.51235+16	0.58654+16	0.75990+16	0.95973+16	0.12919+17	0.12920+17
TH	0.28729+16	0.14383+16	0.76547+15	0.26809+15	0.18174+15	0.13808+15	0.86228+14	0.17971+11	——
U	0.21518+25	0.21520+25	0.21521+25	0.21525+25	0.21532+25	0.21551+25	0.21576+25	0.21665+25	0.21903+25
NP	0.66763+24	0.66810+24	0.66857+24	0.66976+24	0.67213+24	0.67914+24	0.69024+24	0.79531+24	0.83022+24
PU	0.63969+23	0.67232+23	0.68631+23	0.71541+23	0.75975+23	0.82308+23	0.83898+23	0.84979+23	0.10768+24
AM	0.28788+24	0.28816+24	0.28836+24	0.28856+24	0.28802+24	0.28282+24	0.27153+24	0.15597+24	0.54645+23
CM	0.35057+23	0.30897+23	0.28672+23	0.23992+23	0.16992+23	0.69016+22	0.30111+22	0.21972+22	0.11234+22

Time represents cooling time after reprocessing

Table 4 Composition of actinides in HLW from reprocessing fuels with burnup 28,000 MWD/t·UO_2
(g-atom/t)

Time (y) / Element	1	3	5	10	20	50	100	1000	10000
PB	0.34121-08	0.59033-08	0.71809-08	0.85108-08	0.97432-08	0.12623-07	0.15942-07	0.21460-07	0.21462-07
TH	0.47723-08	0.23892-08	0.12715-08	0.44533-09	0.30189-09	0.22937-09	0.14324-09	0.29852-13	0.46158-50
U	0.35744+01	0.35748+01	0.35749+01	0.35756+01	0.35768+01	0.35799+01	0.35840+01	0.35989+01	0.36383+01
NP	0.11090+01	0.11098+01	0.11106+01	0.11126+01	0.11165+01	0.11281+01	0.11466+01	0.13211+01	0.13791+01
PU	0.10626+00	0.11168+00	0.11400+00	0.11884+00	0.12620+00	0.13672+00	0.13937+00	0.14116+00	0.17887+00
AM	0.47821+00	0.47867+00	0.47900+00	0.47933+00	0.47843+00	0.46980+00	0.45105+00	0.25908+00	0.90773-01
CM	0.58234-01	0.51324-01	0.47627-01	0.39854-01	0.28225-01	0.11465-01	0.50019-02	0.36498-02	0.18661-02

Time Represents cooling time after reprocessing

Table 5 Composition of FP in HLW from reprocessing fuels with burnup 33,000 MWD/t·UO_2

(the number of atoms/t)

Element \ Time (y)	1	3	5	10	20	50	100	1000	10000
NI	0.31361E+19	0.29585E+19	0.27963E+19	0.24496E+19	0.19529E+19	0.13088E+19	0.11094E+19	0.10863E+17	0.10863E+19
ZN	0.62674E+19	0.62674E+19	0.62674E+19	0.62674E+19	0.62674E+19	0.62674E+19	0.62674E+19	0.62674E+19	0.62674E+19
GA	0.12978E+20	0.13155E+20	0.13318E+20	0.13664E+20	0.14161E+20	0.14805E+20	0.15004E+20	0.15028E+20	0.15028E+20
GE	0.31834E+22	0.31834E+22	0.31834E+22	0.31839E+22	0.31834E+22	0.31834E+22	0.31834E+22	0.31834E+22	0.31834E+22
AS	0.10103E+22	0.10103E+22	0.10103E+22	0.10103E+22	0.10103E+22	0.10103E+22	0.10103E+22	0.10103E+22	0.10103E+22
SE	0.31834E+24	0.31834E+24	0.31834E+24	0.31834E+24	0.31833E+24	0.31832E+24	0.31830E+24	0.31796E+24	0.31469E+24
BR	0.38459E+18	0.11538E+19	0.19229E+19	0.38457E+19	0.76910E+19	0.19224E+20	0.38439E+20	0.38255E+21	0.36479E+22
KR	0.19412E+18	0.20377E+18	0.20379E+18	0.20379E+18	0.20379E+18	0.20379E+18	0.20379E+18	0.20379E+18	0.20379E+18
RB	0.23667E+25	0.23218E+25	0.22782E+25	0.21742E+25	0.19867E+25	0.15575E+25	0.11415E+25	0.72547E+24	0.72547E+24
SR	0.59555E+25	0.58323E+25	0.57159E+25	0.54519E+25	0.50235E+25	0.42867E+25	0.39296E+25	0.40120E+25	0.40120E+25
Y	0.30991E+25	0.30987E+25	0.30986E+25	0.30985E+25	0.30984E+25	0.30981E+25	0.30979E+25	0.30978E+25	0.30978E+25
ZR	0.23019E+26	0.23186E+26	0.23346E+26	0.23714E+26	0.24330E+26	0.25496E+26	0.26270E+26	0.26600E+26	0.26570E+26
NB	0.21394E+22	0.29460E+21	0.30055E+21	0.31745E+21	0.35126E+21	0.45271E+21	0.62178E+21	0.36642E+22	0.33993E+23
MO	0.21083E+26	0.21087E+26	0.21087E+26	0.21087E+26	0.21087E+26	0.21087E+26	0.21087E+26	0.21087E+26	0.21087E+26
TC	0.51746E+25	0.51745E+25	0.51745E+25	0.51744E+25	0.51743E+25	0.51738E+25	0.51729E+25	0.51578E+25	0.50089E+25
RU	0.13124E+26	0.12898E+26	0.12841E+26	0.12822E+26	0.12822E+26	0.12822E+26	0.12823E+26	0.12838E+26	0.12987E+26
RH	0.27882E+25	0.27882E+25	0.27882E+25	0.27882E+25	0.27882E+25	0.27882E+25	0.27882E+25	0.27882E+25	0.27882E+25
PD	0.73218E+25	0.75477E+25	0.76048E+25	0.76235E+25	0.76241E+25	0.76241E+25	0.76241E+25	0.76250E+25	0.76229E+25
AG	0.44050E+24	0.43986E+24	0.43977E+24	0.43976E+24	0.43976E+24	0.43976E+24	0.43977E+24	0.43987E+24	0.44093E+24
CD	0.41824E+24	0.41888E+24	0.41896E+24	0.41897E+24	0.41896E+24	0.41895E+24	0.41894E+24	0.41894E+24	0.41894E+24
IN	0.87086E+22	0.87127E+22	0.87164E+22	0.87242E+22	0.87350E+22	0.87476E+22	0.87509E+22	0.87512E+22	0.87512E+22
SN	0.22437E+24	0.22414E+24	0.22408E+24	0.22339E+24	0.22369E+24	0.22305E+24	0.22230E+24	0.22060E+24	0.21636E+24
SB	0.75790E+23	0.65639E+23	0.59454E+23	0.52802E+23	0.50609E+23	0.51025E+23	0.51751E+23	0.53009E+23	0.53009E+23
TE	0.24657E+25	0.24758E+25	0.24820E+25	0.24888E+25	0.24912E+25	0.24915E+25	0.24915E+25	0.24919E+25	0.24962E+25
I	0.12843E+24	0.12877E+24	0.12877E+24	0.12877E+24	0.12877E+24	0.12877E+24	0.12877E+24	0.12877E+24	0.12873E+24
XE	0.48255E+16	0.13103E+17	0.21381E+17	0.42075E+17	0.83463E+17	0.20763E+18	0.41457E+18	0.41394E+19	0.41380E+20
CS	0.12834E+26	0.12437E+26	0.12130E+26	0.11542E+26	0.10653E+26	0.89659E+25	0.78041E+25	0.72634E+25	0.72578E+25
BA	0.64294E+25	0.68259E+25	0.71329E+25	0.77211E+25	0.86106E+25	0.10297E+26	0.11459E+26	0.12000E+26	0.12005E+26
LA	0.54518E+25	0.54518E+25	0.54518E+25	0.54518E+25	0.54518E+25	0.54518E+25	0.54518E+25	0.54518E+25	0.54518E+25
CE	0.10687E+26	0.10323E+26	0.10261E+26	0.10249E+26	0.10248E+26	0.10248E+26	0.10248E+26	0.10248E+26	0.10248E+26
PR	0.50801E+25	0.50801E+25	0.50801E+25	0.50801E+25	0.50801E+25	0.50801E+25	0.50801E+25	0.50801E+25	0.50801E+25
ND	0.16518E+26	0.16883E+26	0.16944E+26	0.16956E+26	0.16957E+26	0.16957E+26	0.16957E+26	0.16957E+26	0.16957E+26
PM	0.56815E+24	0.33491E+24	0.19742E+24	0.52671E+23	0.37491E+22	0.13534E+19			
SM	0.29234E+25	0.31560E+25	0.32930E+25	0.34364E+25	0.34827E+25	0.34798E+25	0.34715E+25	0.34531E+25	0.34530E+25
EU	0.66444E+24	0.63349E+24	0.60859E+24	0.56549E+24	0.52547E+24	0.50784E+24	0.51455E+24	0.53293E+24	0.53295E+24
GD	0.30471E+24	0.33622E+24	0.36168E+24	0.40615E+24	0.44875E+24	0.47309E+24	0.47469E+24	0.47473E+24	0.47478E+24
TB	0.97580E+22	0.97563E+22	0.97562E+22	0.97558E+22	0.97552E+22	0.97533E+22	0.97504E+22	0.97189E+22	0.96670E+22
DY	0.50206E+22	0.50221E+22	0.50221E+22	0.50222E+22	0.50223E+22	0.50225E+22	0.50230E+22	0.50292E+22	0.50397E+22
HO	0.59855E+20	0.59839E+20	0.59820E+20	0.59772E+20	0.59675E+20	0.59390E+20	0.58927E+20	0.52516E+20	0.43990E+20
ER	0.39731E+20	0.39744E+20	0.39757E+20	0.39770E+20	0.39857E+20	0.40053E+20	0.40372E+20	0.44789E+20	0.51232E+20

Time represents cooling time after reprocessing

Table 6 Composition of FP in HLW from reprocessing fuels with burnup 33,000 MWD/t·UO_2 (g-atom/t)

Time (y) / Element	1	3	5	10	20	50	100	1000	10000
NI	0.52069E-05	0.49120E-05	0.46427E-05	0.40671E-05	0.32423E-05	0.21731E-05	0.18419E-05	0.18036E-05	0.18036E-05
ZN	0.10406E-04	0.10406E-04	0.10406E-04	0.10406E-04	0.10406E-04	0.10406E-04	0.10406E-04	0.10406E-04	0.10406E-04
GA	0.21547E-04	0.21842E-04	0.22111E-04	0.22687E-04	0.23512E-04	0.24581E-04	0.24912E-04	0.24950E-04	0.24950E-04
GE	0.52854E-02	0.52854E-02	0.52854E-02	0.52854E-02	0.52854E-02	0.52854E-02	0.52854E-02	0.52854E-02	0.52854E-02
AS	0.16774E-02	0.16774E-02	0.16774E-02	0.16774E-02	0.16774E-02	0.16774E-02	0.16774E-02	0.16774E-02	0.16774E-02
SE	0.52854E+00	0.52854E+00	0.52854E+00	0.52854E+00	0.52853E+00	0.52851E+00	0.52848E+00	0.52791E+00	0.52249E+00
BR	0.63854E-06	0.19157E-05	0.31926E-05	0.63850E-05	0.12769E-04	0.31918E-04	0.63820E-04	0.63515E-03	0.60566E-02
KR	0.32230E-06	0.33832E-06	0.33836E-06	0.33836E-06	0.33836E-06	0.33836E-06	0.33836E-06	0.33836E-06	0.33836E-06
RB	0.39294E+01	0.38548E+01	0.37825E+01	0.36098E+01	0.32985E+01	0.25860E+01	0.18952E+01	0.12045E+01	0.12045E+01
SR	0.98879E+01	0.96834E+01	0.94902E+01	0.90519E+01	0.83405E+01	0.71171E+01	0.65243E+01	0.66611E+01	0.66611E+01
Y	0.51454E+01	0.51447E+01	0.51447E+01	0.51445E+01	0.51442E+01	0.51437E+01	0.51434E+01	0.51433E+01	0.51433E+01
ZR	0.38219E+02	0.38496E+02	0.38762E+02	0.39373E+02	0.40396E+02	0.42332E+02	0.43615E+02	0.44164E+02	0.44114E+02
NB	0.35521E-02	0.48913E-03	0.49900E-03	0.52707E-03	0.58320E-03	0.75164E-03	0.10323E-02	0.60838E-02	0.56439E-01
MO	0.35005E+02	0.35011E+02	0.35011E+02	0.35011E+02	0.35011E+02	0.35011E+02	0.35011E+02	0.35011E+02	0.35011E+02
TC	0.85914E+01	0.85912E+01	0.85912E+01	0.85911E+01	0.85909E+01	0.85901E+01	0.85886E+01	0.85635E+01	0.83163E+01
RU	0.21789E+02	0.21419E+02	0.21320E+02	0.21289E+02	0.21288E+02	0.21289E+02	0.21290E+02	0.21315E+02	0.21562E+02
RH	0.46293E+01	0.46293E+01	0.46293E+01	0.46293E+01	0.46293E+01	0.46293E+01	0.46293E+01	0.46293E+01	0.46293E+01
PD	0.12156E+02	0.12531E+02	0.12626E+02	0.12657E+02	0.12658E+02	0.12658E+02	0.12658E+02	0.12658E+02	0.12656E+02
AG	0.73137E+00	0.73029E+00	0.73015E+00	0.73013E+00	0.73013E+00	0.73014E+00	0.73015E+00	0.73032E+00	0.73207E+00
CD	0.69440E+00	0.69547E+00	0.69560E+00	0.69562E+00	0.69560E+00	0.69558E+00	0.69557E+00	0.69557E+00	0.69557E+00
IN	0.14459E-01	0.14466E-01	0.14472E-01	0.14485E-01	0.14503E-01	0.14524E-01	0.14529E-01	0.14530E-01	0.14530E-01
SN	0.37252E+00	0.37214E+00	0.37204E+00	0.37182E+00	0.37139E+00	0.37033E+00	0.36909E+00	0.36627E+00	0.35922E+00
SB	0.12583E+00	0.10898E+00	0.98711E-01	0.87666E-01	0.84027E-01	0.84717E-01	0.85922E-01	0.88011E-01	0.88011E-01
TE	0.40938E+01	0.41105E+01	0.41209E+01	0.41321E+01	0.41362E+01	0.41366E+01	0.41366E+01	0.41373E+01	0.41444E+01
I	0.21323E+00	0.21379E+00	0.21380E+00	0.21380E+00	0.21380E+00	0.21380E+00	0.21380E+00	0.21379E+00	0.21373E+00
XE	0.80117E-08	0.21755E-07	0.35499E-07	0.69857E-07	0.13857E-06	0.34473E-06	0.68831E-06	0.68726E-05	0.68703E-04
CS	0.21308E+02	0.20650E+02	0.20140E+02	0.19164E+02	0.17687E+02	0.14886E+02	0.12957E+02	0.12059E+02	0.12050E+02
BA	0.10675E+02	0.11333E+02	0.11843E+02	0.12819E+02	0.14296E+02	0.17097E+02	0.19026E+02	0.19923E+02	0.19933E+02
LA	0.90516E+01	0.90516E+01	0.90516E+01	0.90516E+01	0.90516E+01	0.90516E+01	0.90516E+01	0.90516E+01	0.90516E+01
CE	0.17744E+02	0.17139E+02	0.17036E+02	0.17016E+02	0.17016E+02	0.17016E+02	0.17016E+02	0.17016E+02	0.17016E+02
PR	0.84345E+01	0.84345E+01	0.84345E+01	0.84345E+01	0.84345E+01	0.84345E+01	0.84345E+01	0.84345E+01	0.84345E+01
ND	0.27425E+02	0.28030E+02	0.28132E+02	0.28153E+02	0.28153E+02	0.28153E+02	0.28153E+02	0.28153E+02	0.28153E+02
PM	0.94331E+00	0.55605E+00	0.32778E+00	0.87450E-01	0.62246E-02	0.22470E-05			
SM	0.48537E+01	0.52300E+01	0.54673E+01	0.57054E+01	0.57823E+01	0.57775E+01	0.57637E+01	0.57331E+01	0.57331E+01
EU	0.11032E+01	0.10518E+01	0.10104E+01	0.93888E+00	0.87244E+00	0.84316E+00	0.85431E+00	0.88483E+00	0.88486E+00
GD	0.50590E+00	0.55823E+00	0.60049E+00	0.67433E+00	0.74506E+00	0.78547E+00	0.78812E+00	0.78820E+00	0.78827E+00
TB	0.16201E-01	0.16198E-01	0.16198E-01	0.16198E-01	0.16197E-01	0.16193E-01	0.16189E-01	0.16136E-01	0.16050E-01
DY	0.83357E-02	0.83382E-02	0.83382E-02	0.83383E-02	0.83385E-02	0.83389E-02	0.83396E-02	0.83500E-02	0.83674E-02
HO	0.99383E-04	0.99351E-04	0.99320E-04	0.99240E-04	0.99079E-04	0.98606E-04	0.97837E-04	0.87359E-04	0.73037E-04
ER	0.65966E-04	0.65988E-04	0.66009E-04	0.66064E-04	0.66175E-04	0.66501E-04	0.67030E-04	0.74364E-04	0.85061E-04

Time represents cooling time after reprocessing

Table 7 Composition of actinides in HLW from reprocessing fuels with burnup 33,000 MWD/t·UO_2 (the number of atoms/t)

Time (y) / Element	1	3	5	10	20	50	100	1000	10000
PB	0.38088+16	0.64315+16	0.77633+16	0.90918+16	0.10190+17	0.12676+17	0.15541+17	0.20304+17	0.20305+17
TH	0.50336+16	0.25056+16	0.13127+16	0.41976+15	0.26154+15	0.19796+15	0.12362+15	0.25764+11	——
U	0.21411+25	0.21413+25	0.21415+25	0.21421+25	0.21432+25	0.21460+25	0.21497+25	0.21642+25	0.22062+25
NP	0.80755+24	0.80814+24	0.80873+24	0.81021+24	0.81316+24	0.82188+24	0.83566+24	0.96624+24	0.10110+25
PU	0.72280+23	0.78692+23	0.82184+23	0.89567+23	0.10067+24	0.11637+24	0.12106+24	0.12409+24	0.16462+24
AM	0.41493+24	0.41518+24	0.41535+24	0.41542+24	0.41451+24	0.40768+24	0.39335+24	0.24559+24	0.91568+23
CM	0.71278+23	0.63800+23	0.59320+23	0.49810+23	0.35581+23	0.15082+23	0.71863+22	0.54744+22	0.27991+22

Time represents cooling time after reprocessing

Table 8 Composition of actinides in HLW from reprocessing fuels with burnup 33,000 MWD/t·UO_2 (g-atom/t)

Time (y) / Element	1	3	5	10	20	50	100	1000	10000
PB	0.63269-08	0.10684-07	0.12896-07	0.15103-07	0.16927-07	0.21056-07	0.25816-07	0.33728-07	0.33729-07
TH	0.83615-08	0.41621-08	0.21806-08	0.69728-09	0.43445-09	0.32884-09	0.20535-09	0.42797-13	0.66173-50
U	0.35566+01	0.35570+01	0.35573+01	0.35583+01	0.35601+01	0.35649+01	0.35710+01	0.35950+01	0.36649+01
NP	0.13414+01	0.13424+01	0.13434+01	0.13459+01	0.13508+01	0.13652+01	0.13881+01	0.16051+01	0.16795+01
PU	0.12007+00	0.13072+00	0.13652+00	0.14878+00	0.16722+00	0.19331+00	0.20110+00	0.20613+00	0.27346+00
AM	0.68924+00	0.68967+00	0.68994+00	0.69007+00	0.68855+00	0.67720+00	0.65340+00	0.40796+00	0.15211+00
CM	0.11840+00	0.10598+00	0.98538-01	0.82741-01	0.59105-01	0.25053-01	0.11937-01	0.90937-02	0.46497-02

Time represents cooling time after reprocessing

Table 9 Composition of HLLW at 500 l/t·UO_2

Element		Concentration (g-atom/l-HLLW) 28GWD/t	33GWD/t
Fission products	Se	9.68E-4	1.06E-3
	Rb	6.41 -3	7.57 -3
	Sr	1.61 -2	1.90 -2
	Y	8.73 -3	1.30 -2
	Zr	6.57 -2	7.75 -2
	Mo	5.94 -2	7.00 -2
	Tc	1.47 -2	1.72 -2
	Ru	3.60 -2	4.26 -2
	Rh	8.26 -3	9.26 -3
	Pd	2.11 -2	2.53 -2
	Ag	1.23 -3	1.46 -3
	Cd	1.14 -3	1.39 -3
	Sn	6.28 -4	7.44 -4
	Sb	1.70 -4	1.97 -4
	Te	6.99 -3	8.24 -3
	Cs	3.45 -2	4.03 -2
	Ba	1.98 -2	2.37 -2
	La	1.54 -2	1.81 -2
	Ce	2.89 -2	3.41 -2
	Pr	1.43 -2	1.69 -2
	Nd	4.77 -2	5.63 -2
	Pm	6.20 -4	6.56 -4
	Sm	9.38 -3	1.09 -2
	Eu	1.66 -3	2.02 -3
	Gd	9.07 -4	1.20 -3
Actinides	U	7.15 -3	7.11 -3
	Np	2.22 -3	2.69 -3
	Pu	2.28 -4	2.73 -4
	Am	9.58 -4	1.38 -3
	Cm	9.53 -5	1.97 -4
Inerts	Na	5.97 -1	5.97 -1
	P	2.63 -2	2.63 -2
	Fe	1.94 -1	1.94 -1
	Cr	2.96 -2	2.96 -2
	Ni	2.61 -2	2.61 -2
	HNO_3	2.00 +0	2.00 +0

Cooling time until reprocessing; 180 days

Cooling time after reprocessing; 5 years

Table 10 Constituents of simulated HLLW

Waste elments		Simulated wastes		
		JW-A	JW-B	JW-C
Fission products	Se (+4)	Se	—	—
	Rb (+1)	Rb	Rb	K (+1)
	Sr (+2)	Sr	Sr	Sr
	Y (+3)	Y	RE	Ca (+2)
	Zr (+4)	Zr	Zr	Zr
	Mo (+6)	Mo	Mo	Mo
	Tc	Mn (+4)	Mn	Mn
	Ru (+4)	Ru	Fe (+2, +3)	Fe
	Rh (+3)	Rh	Co (+3)	Co
	Pd (+2)	Pd	Ni (+2)	Ni
	Ag (+1)	Ag	Ag	—
	Cd (+2)	Cd	Cd	—
	Sn (+4)	Sn	—	—
	Sb (+3)	Sb	—	—
	Te (+4)	Te	Te	Te
	Cs (+1)	Cs	Cs	Cs
	Ba (+2)	Ba	Ba	Ba
	La (+3)	La	RE	Ca (+2)
	Ce (+4)	Ce	RE	Ca
	Pr (+3)	Pr	RE	Ca
	Nd (+3)	Nd	RE	Ca
	Pm (+3)	Nd (+3)	RE	Ca
	Sm (+3)	Sm	RE	Ca
	Eu (+3)	Eu	RE	Ca
	Gd (+3)	Gd	RE	Ca
Actinides	U (+3, +4)	Ce (+3, +4)	RE	Ca
	Np (+3, +4)	Ce	RE	Ca
	Pu (+3, +4)	Ce	RE	Ca
	Am (+3, +4)	Ce	RE	Ca
	Cm (+3)	Ce	RE	Ca
Inerts	Na (+1)	Na	Na	Na
	P (+5)	P	P	P
	Fe (+2, +3)	Fe	Fe	Fe
	Cr (+3)	Cr	Cr	Cr
	Ni (+2)	Ni	Ni	Ni
	HNO_3	HNO_3	HNO_3	HNO_3

RE represents the mixed rara-earth.
( ) represents the atomic valence

Table 11 Compositions of simulated HLLW at 500 l/t·UO_2

Waste elements		JW-A Compound used	JW-A Molar concentration 28GWD/t	JW-A Molar concentration 33GWD/t	JW-B Compound used	JW-B Molar concentration 28GWD/t	JW-B Molar concentration 33GWD/t	JW-C Compound used	JW-C Molar concentration 28GWD/t	JW-C Molar concentration 33GWD/t
Fission Products	Se	SeO_2	9.68 E−4	1.06 E−3	—	—	—	—	—	—
	Rb	$RbNO_3$	6.41 −3	7.57 −3	$RbNO_3$	6.41 E−3	7.57 E−3	KNO_3	6.41 E−3	7.57 E−3
	Sr	$Sr(NO_3)_2$	1.61 −2	1.90 −2	$Sr(NO_3)_2$	1.61 −2	1.90 −2	$Sr(NO_3)_2$	1.61 −2	1.90 −2
	Y	$Y(NO_3)_3 \cdot 6H_2O$	8.73 −3	1.03 −2	$RE(NO_3)_3 \cdot 6H_2O$	8.73 −3	1.03 −2	$CaCO_3$	8.73 −3	1.03 −2
	Zr	$ZrO(NO_3)_2 \cdot 2H_2O$	6.57 −2	7.75 −2	$ZrO(NO_3)_2 \cdot 2H_2O$	6.57 −2	7.75 −2	$ZrO(NO_3)_2 \cdot 2H_2O$	6.57 −2	7.75 −2
	Mo	$H_2MoO_4 \cdot H_2O$	5.94 −2	7.00 −2	$H_2MoO_4 \cdot H_2O$	5.94 −2	7.00 −2	$H_2MoO_4 \cdot H_2O$	5.94 −2	7.00 −2
	Tc	$Mn(NO_3)_2 \cdot 6H_2O$	1.47 −2	1.72 −2	$Mn(NO_3)_2 \cdot 6H_2O$	1.47 −2	1.72 −2	$Mn(NO_3)_2 \cdot 6H_2O$	1.47 −2	1.72 −2
	Ru	$RuCl_3 \cdot 3H_2O$	3.60 −2	4.26 −2	$Fe(NO_3)_3 \cdot 9H_2O$	3.60 −2	4.26 −2	$Fe(NO_3)_3 \cdot 9H_2O$	3.60 −2	4.26 −2
	Rh	$Rh(NO_3)_3 \cdot 2H_2O$	8.26 −3	9.26 −3	$Co(NO_3)_2 \cdot 6H_2O$	8.26 −3	9.26 −3	$Co(NO_3)_2 \cdot 6H_2O$	8.26 −3	9.26 −3
	Pd	$Pd(NO_3)_2$	2.11 −2	2.53 −2	$Ni(NO_3)_2 \cdot 6H_2O$	2.11 −2	2.53 −2	$Ni(NO_3)_2 \cdot 6H_2O$	2.11 −2	2.53 −2
	Ag	$AgNO_3$	1.23 −3	1.46 −3	$AgNO_3$	1.23 −3	1.46 −3	—	—	—
	Cd	$Cd(NO_3)_2$	1.14 −3	1.39 −3	$Cd(NO_3)_2$	1.14 −3	1.39 −3	—	—	—
	Sn	$SnCl_4 \cdot 5H_2O$	6.28 −4	7.44 −4	—	—	—	—	—	—
	Sb	$SbCl_3$	1.70 −4	1.97 −4	—	—	—	—	—	—
	Te	TeO_2	6.99 −3	8.24 −3	TeO_2	6.99 −3	8.24 −3	TeO_2	6.99 −3	8.24 −3
	Cs	$CsNO_3$	3.45 −2	4.03 −2	$CsNO_3$	3.45 −2	4.03 −2	$CsNO_3$	3.45 −2	4.03 −2
	Ba	$Ba(NO_3)_2$	1.98 −2	2.37 −2	$Ba(NO_3)_2$	1.98 −2	2.37 −2	$Ba(NO_3)_2$	1.98 −2	2.37 −2
	La	$La(NO_3)_3 \cdot 6H_2O$	1.54 −2	1.81 −2						
	Ce	$Ce(NO_3)_3 \cdot 6H_2O$	2.89 −2	3.41 −2						
	Pr	$Pr(NO_3)_3 \cdot 6H_2O$	1.43 −2	1.69 −2						
	Nd	$Nd(NO_3)_3 \cdot 6H_2O$	4.77 −2	5.63 −2	$RE(NO_3)_3 \cdot 6H_2O$	1.19 −1	1.40 −1	$CaCO_3$	1.19 −1	1.40 −1
	Pm	$Nd(NO_3)_3 \cdot 6H_2O$	6.38 −4	6.56 −4						
	Sm	$Sm(NO_3)_3 \cdot 6H_2O$	9.38 −3	1.09 −2						
	Eu	$Eu(NO_3)_3 \cdot 6H_2O$	1.66 −3	2.02 −3						
	Gd	$Gd(NO_3)_3 \cdot 6H_2O$	9.07 −4	1.20 −3						
Actinides	U									
	Np									
	Pu	$Ce(NO_3)_3 \cdot 6H_2O$	1.07 −2	1.17 −2	$RE(NO_3)_3 \cdot 6H_2O$	1.07 −2	1.17 −2	$CaCO_3$	1.07 −2	1.17 −2
	Am									
	Cm									
Inerts	Na	$NaNO_3$	5.97 −11	5.97 −1	$NaNO_3$	5.97 −1	5.97 −1	$NaNO_3$	5.97 −1	5.97 −1
	P	H_3PO_4	2.63 −2	2.63 −2	H_3PO_4	2.63 −2	2.63 −2	H_3PO_4	2.63 −2	2.63 −2
	Fe	$Fe(NO_3)_3 \cdot 9H_2O$	1.94 −1	1.94 −1	$Fe(NO_3)_3 \cdot 9H_2O$	1.94 −1	1.94 −1	$Fe(NO_3)_3 \cdot 9H_2O$	1.94 −1	1.94 −1
	Cr	$Cr(NO_3)_3 \cdot 9H_2O$	2.96 −2	2.96 −2	$Cr(NO_3)_3 \cdot 9H_2O$	2.96 −2	2.96 −2	$Cr(NO_3)_3 \cdot 9H_2O$	2.96 −2	2.96 −2
	Ni	$Ni(NO_3)_2 \cdot 6H_2O$	2.61 −2	2.61 −2	$Ni(NO_3)_2 \cdot 6H_2O$	2.61 −2	2.61 −2	$Ni(NO_3)_2 \cdot 6H_2O$	2.61 −2	2.61 −2
	HNO_3	HNO_3	2.00 +0	2.00 +0	HNO_3	2.00 +0	2.00 +0	HNO_3	2.00 +0	2.00 +0

Cooling time until reprocessing; 180 days
Cooling time after reprocessing; 5 years

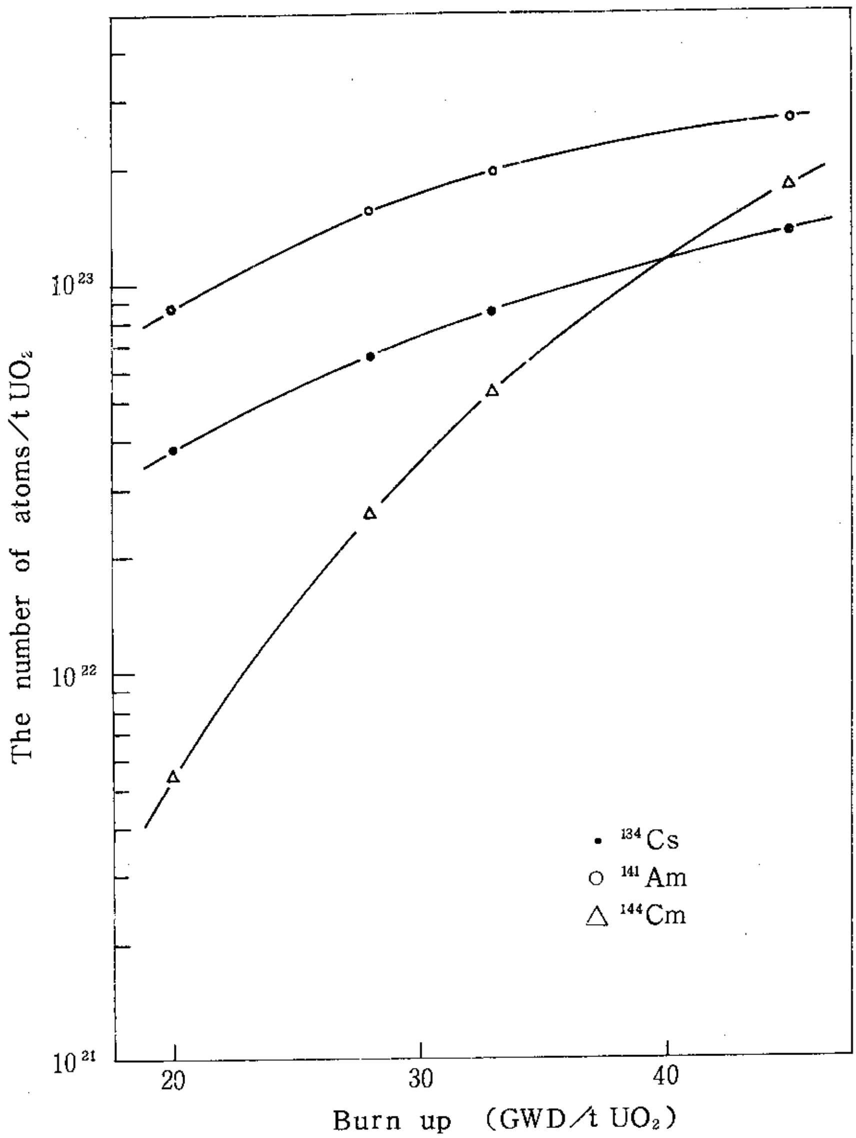

Fig. 1 Relation between the amount of multineutron capture products (^{134}Cs, ^{141}Am, ^{144}Cm) and burn-up. (Cooling time after reprocessing ; 5 years)