CANFLEX-RU FUEL DEVELOPMENT PROGRAM AS ONE OPTION OF ADVANCED FUEL CYCLES IN KOREA

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Abstract

As one of the possible fuel cycles in Korea, RU (Recycled Uranium) fuel offers a very attractive alternative to the use of NU (Natural Uranium) and SEU in the CANDU reactors, because Korea is a unique country having both PWR and CANDU reactors. Korea can therefore exploit the natural synergism between the two reactor types to minimise overall waste production, and maximise energy derived from the fuel, by burning the spent fuel from its PWR reactors in CANDU reactors. Potential benefits can be derived from a number of stages in the fuel cycle: no enrichment required, no enrichment tails, direct conversion to $U0_2$, lower sensitivity to ^{234}U and ^{236}U absorption in the CANDU reactor, expected lower cost relative to NU and SEU. These benefits all fit well with the PWR-CANDU fuel cycle synergy. RU arising from the reprocessing of European and Japanese oxide spent fuel by 2000 is projected to be approaching 25,000 te. The use of RU fuel in a CANDU-6 reactor should result in no serious radiological difficulties and no requirements for special precautions and should not require any new technologies for the fuel fabrication and handling. A KAERI's feasibility shows that the use of the CANFLEX bundle as the carrier for RU will be compatible with the reactor design, current safety and operational requirements, and there will be no significant fuel performance difference from the CANDU 37-element NU fuel bundle. Compared with the 37-element NU bundle, the RU fuel has significantly improved fuel cycle economics derived from increased burnups, a large reduction in fuel requirements and spent fuel arisings and the potential lower cost for RU material. There is the potential for annual fuel cost savings to be in the range of one-third to two-thirds, with enhanced operating margins using RU in the CANFLEX bundle design. These benefits provide the rationale for justifying R & D effort on the use of RU fuel for advanced fuel cycles in the CANDU reactors of Korea. The RU fuel development is an international collaboration between KAERI, AECL and BNFL. It is expected that the work will be completed before 2005, and there should be no impediment to the use of RU fuel in the CANDU-6 reactors in Korea, if the RU in the world is available and competitive with NU and SEU on price.

1. INTRODUCTION

In Korea, twelve nuclear power plants, (10 PWRs and 2 CANDUs) are currently in operation, and six plants (4 PWRs and 2 CANDUs) are under construction. In 1997, the existing power plants represent about 25 % (10,316 MW) of the domestic installed generating capacity, and produced about 34 % (77,086 GWh) of the gross electrical energy generation. In 2002, a total nuclear power generation capacity of 15,742 MWe will be installed in Korea, where 18 % of the capacity will be contributed by the 4 Wolsong CANDUs. Korea is therefore a unique country in the world having both PWR and CANDU reactors, and can exploit the natural synergism between these two reactor types to minimise overall waste production, and maximise energy derived from the fuel. The synergism can be exploited through several different fuel cycles [1]. In conventional reprocessing, which is currently available from several sources, uranium and plutonium are separated from the fission products and other actinides in the spent fuel. The plutonium could be recycled as MOX fuel, in either LWR's or in CANDU reactors. If the political and non-proliferation considerations in the Korean peninsula led to the decision to reprocess the Korean spent PWR fuel, then the resultant recovered uranium, which constitutes the vast majority of the spent fuel, and which still contains valuable ^{235}U (typically about 0.9%), could be recycled as-is in CANDU reactors, without re-enrichment. The fuel burnup in CANDU would be about double that of natural uranium fuel, and about twice the energy would be extracted, compared with re-enrichment and recycling in a PWR. However, the use of RU in Korean CANDU reactors is not dependent on reprocessing Korean spent PWR fuel; RU is a nuclear fuel commodity available from several sources, as is natural uranium, and enriched uranium. Hence, RU as a fuel cycle option in Korea is particularly attractive for use in the CANDU reactors, with the advantage of potentially lower fuelling costs than both NU and SEU.

KAERI (Korea Atomic Energy Research Institute) has a comprehensive product development program on CANFLEX (CANDU Flexible Fuelling) - RU (Recovered Uranium) fuel[2]. This is seen as an economical alternative to natural uranium as a fuel for use in either existing or future CANDU reactors. The aim is to introduce CANFLEX into CANDU reactors in Korea and have a clear vision of how the product will evolve over the next 10 years. The key targets of the program are enhanced safety and economics, the reduction of spent fuel volumes, using the inherent characteristics and advantages of CANDU technology. The specific activities of the program take account of the domestic and international environment concerning non-proliferation in the Peninsula of Korea[2]. These involve showing an overall evaluation and identification of the potential benefits, risks, and costs associated with the use of RU fuel to a CANDU-6 utility by 1999. This will provide a rationale to justify the R & D efforts on it for the advanced fuel cycle of CANDU reactors in Korea. The justification includes security of supply issues for RU and the overall possibility of satisfying the licensing issues in the Korea Safety Review Guideline (KSRG)[3]. These external influences and justifications have been, and will be applied to all fuel and fuel cycle R & D in Korea. The RU fuel R & D program has been enhanced by an international collaboration between KAERI, AECL(Atomic Energy of Canada Limited) and BNFL(British Nuclear Fuels Plc), since the end of 1996. The prime objective of this joint program is the small-scale demonstration irradiation of 20 to 100 bundles in a CANDU power reactor, followed by the post irradiation examination of selected irradiated bundles. This is a necessary prerequisite to a full-scale conversion to RU. The program includes the necessary analysis and out-of-reactor tests.

The intent of this paper is to evaluate the advantages and feasibility of CANFLEX-RU in order to provide a rationale for justifying the R & D efforts on it for an advanced fuel cycle in Korea.

2. CANFLEX AS THE REFERENCE CARRIER OF RU IN CANDU

To allow the benefits of RU to be maximised, an appropriate carrier is required. This is achieved through the provision of enhanced operating margins in the CANFLEX bundle design [4]. Since 1991, KAERI and AECL have pursued a collaborative program to develop, verify and prove the design of CANFLEX which is a 43 element CANDU fuel bundle and acts as the reference carrier of the RU fuel. The CANFLEX bundle has the same bundle diameter and length as a CANDU-6 37-element natural uranium (NU) bundle. The principle features of CANFLEX are enhanced thermalhydraulic performance and more balanced radial power distribution, providing CANDU plant operators with greater operating flexibility through improved operating margins. Critical heat flux (CHF) enhancement appendages on the bundle enable a higher bundle before CHF occurs, leading to a net gain in the critical channel power of 6 % to 8 % over the existing 37-element fuel bundle. The maximum linear element rating in a CANFLEX bundle is 20 % lower than that of the conventional bundle, reducing the consequences of most design-basis accidents. The lower element rating is achieved by adding extra elements and using larger diameter element in the 2 center rings and smaller diameter ones in the outer 2 rings. These features will provide larger operating margins in existing CANDUs, and will allow higher burnups. New Brunswick Power at the Point Lepreau Generating Station in Canada will irradiate 24 CANFLEX-NU fuel bundles over a 2-years period starting in 1998, as a final verification of CANFLEX design in preparation for full-core conversion [5].

3. CANDU-6 REACTOR PHYSICS, THERMALHYDRAULICS, SAFETY AND FUEL PERFORMANCE OF CANFLEX-RU

AECL and KAERI have performed reactor physics simulations to evaluate the feasibility of CANFLEX-RU fuel being used in a CANDU-6 reactor by taking the isotopic composition of typical RU UO_2 produced by the MDR route.

RU is one of the products of conventional chemical reprocessing of spent uranium oxide fuel. The extra isotopes in RU have minimal effect on the reactor physics characteristics in CANDU. Spent PWR fuel contains typically 0.4 % ^{236}U with a range from 0.2 % to 0.7 %, originating from neutron capture in ^{235}U in the original PWR fuel, that has a strong resonance at 5.5 eV. Because of the softer neutron spectrum in a CANDU reactor, the absorption worth of the ^{236}U is an order of magnitude lower in a CANDU than in a PWR. Also, the ^{235}U would be burned down to low levels (i.e. 0.2 to 0.3 %) in a CANDU reactor because of the good neutron economics provided by the heavy water moderator and coolant, compared with PWRs (0.8 % to 1.0 %)[6]. Therefore, the main determinant in CANDU reactor physics with RU is the ^{235}U level.

In AECL[7], 500 FPD (Full Power Days) core-follow simulations were made for CANFLEX-RU with 0.96 w/o ^{235}U, using a bi-directional 2-bundle-shift refuelling scheme, where standard computer codes and methods were used for the simulations and analysis. WIMS-AECL[8] with ENDF/B-V nuclear data library was used to construct fuel tables for use with a core code, RFSP[9], which modelled the reactor core. To facilitate the decisions that must be made during refuelling, an automated method was used to do most of the editing and calculations required to perform the steps. The results of the CANFLEX-RU core-follow simulations show that the RU fuel would be a satisfactory fuel in a CANDU-6 equilibrium core : maximum bundle power of 857 kW(c.f. the license limit of 935 kW); maximum chnnel power of 7.021 MW (c.f. the license limit of 7.3 MW); average discharge burnup of 1394 MWd/kgU. An assessment was made of the probability of stress-corrosion cracking (SCC) through power boosting using the results of the AECL refuelling simulation. The CANFLEX-RU elements do not come close to approaching the SCC element-power threshold, and none of the linear-element powers were above 44 kW/m as shown in Fig. 1.

In KAERI, the reactor lattice calculations for various bundle types of CANFLEX-0.9 % RU were preliminarily performed with WIMS-AECL code to investigate the bundle types with respect to Korean safety regulation of power coefficient. The results of the WIMS-AECL reactor lattice calculations show that the power coefficient of the CANFLEX bundle type with RU in all elements is positively increased, compared with that of a 37-element fuel bundle with natural uranium as shown in Table 1. However, the power coefficient of a CANFLEX-RU bundle with, for example, stainless steel in the centre element is negatively increased, compared with that of the 37-element fuel bundle. RFSP time-averaged (reaction rate averaged) calculation results maximum bundle power of 775 kW (c.f. the licence limit of 935 kW), maximum channel power of 6.57 MW (c.f. the licence limit of 7.3 MW) and average discharge bunrup of 13,375 MWd/MTU which is 88 % higher than that of the 37-element fuel bundle with natural uranium. Statistic reactivity worths of adjuster rods, zone controllers and mechanical control absorbers in CANDU-6 equilibrium core were investigated for the CANFLEX-RU bundle with 0.90 w/o ^{235}U, using with a bi-directional 4-bundle-shift refuelling

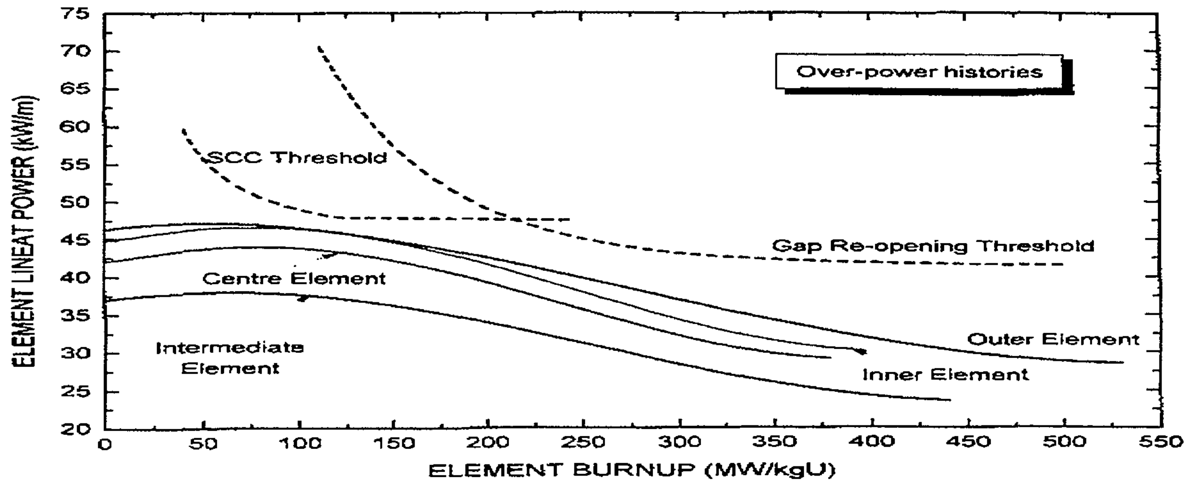

Fig. 1. Defect Analysis of CANFLEX-RU(0.98 % U-235 in total U) Fuel Bundle With Respect To SCC Threshold

Table 1. Characteristics of WIMS-AECL Time-Averaged Lattice Parameters for CANDU-6 Existing Fuel and Possible Bundle Types of CANFLEX-RU

Fuel Types	MLHR (kW/m)	Coolant Void Reactivity (mk)	Fuel Temp. Coeff. (mk/^{o}C)	Coolant Temp. Coeff. (mk/^{o}C)	Moderator Temp. Coeff. (mk/^{o}C)	Average Discharge Burnup (MWd/MtU)	Power Coeff. (mk/%FP)
37-elem.(NU37)	58.031	14.49664	-0.00123	0.05302	0.02870	7,087	~0.0
CANFLEX(NU43)	48.879	15.51087	-0.00143	0.05616	0.02987	7,002	-0.001096
CANFLEX(RU43)	49.398	15.91435	-0.00104	0.05919	0.03937	13,040	0.002872
CANFLEX (C1+RU42)	51.319	15.44110	-0.00114	0.05810	0.03910	12,993	0.001792
CANFLEX (C8+RU35)	57.206	12.69371	-0.00146	0.05132	0.04217	12,389	-0.002323
CANFLEX (ST1+RU42)	50.682	13.39525	-0.00207	0.05188	0.01972	10,474	-0.007426
CANFLEX (Fe 1+RU42)	50.792	13.73889	-0.00190	0.05305	0.02313	10,889	-0.005730
CANFLEX (Al 1+RU42)	51.245	15.32182	-0.00116	0.05764	0.03847	12,820	0.001552
Remarks	NU : Natural Uranium; RU : Recovered Uranium(0.9 %U-235 in total U); C : Graphite rod in center or inner ring; ST : Stainless steel rod in center ring; Fe : Iron rod in center ring; Al : Aluminium rod in center ring, X# : Number of rods						

Table 2. Static Reactivity Worth of Reactivity Control System in CANDU-6 Equilibrium Core

Fuel Types	Adjuster Rods	Zone Controllers	Mechanical Control Absorbers
37-elem. (NU37)	16.6 mk (> Xe buildup:13 mk)	6.5 mk	-11.3 mk
CANFLEX (RU43)	14.7 mk (> Xe buildup:12 mk)	7.3 mk	-8.5 mk
Remarks	Compatible with CANDU-6 design	Compatible with CANDU-6 design	Required to be investigated in more detail

scheme. In CANDU-6, the adjuster rods are provided for xenon override capability needed to restart the reactor after a short shutdown, power manoeuvering during startup or power derating, reactivity shim when fuelling is temporarily interrupted, and shaping the thermal flux distribution in the core for optimum reactor power and fuel burnup. The light water zone control system is designed to perform two main functions: bulk control (control of gross power output) and spatial control (control of flux/power shape). The mechanical control absorbers are to initiate rapid power reduction if required by operations and to override the reactivity increase following a power reduction (due to the negative fuel temperature coefficient). As shown in Table 2 , the CANFLEX –0.9 % RU bundles would not required any design change or hardware modification in CANDU-6 reactor, even if the mechanical control absorbers are required in more details of investigation for the static reactivity worth. In addition, criticality of the fresh fuel on the reactor site and criticality and heat removal capability of the irradiated fuel in the storage pool are investigated to be that there are no requirement of any design or hardware modifications of the reactor site. Based on the results of RFSP time-averaged (reaction rate averaged) calculation, the radial and axial heat flux distributions for the CANDU-6 equilibrium core with the CANFLEX-RU fuel led to increase critical channel power by about 4 %, compared with the CANDU-6 equilibrium core with the 37-element natural uranium fuel. A CANDU fuel element performance analysis code, ELESTRES [10], predicted that the internal pressure of the outer CANFLEX-RU elements in normal power operation was below 2.5 MPa, which is lower than that of the outer elements of the 37-element NU fuel bundle by a factor of 2. The maximum fuel stack length of the outer and inner CANFLEX-RU elements increased by 0.46 % through thermal expansion, which is equivalent to a reduction of less than 0.2 mm in the axial gap between the fuel stack and the end cap. A preliminary safety assessment of a CANDU-6 shows that, for all the shorter half-life isotopes, the gap (or "free") inventory with CANFLEX-RU fuel is 5 - 10 times smaller than that for 37-element NU fuel, and the total inventory with RU-fuel is very similar to that for 37-element NU fuel. For the longer half-life isotopes such as ^{137}Cs, the gap inventory with CANFLEX-RU is very similar to that with 37-element NU fuel, but the total inventory with CANFLEX RU fuel is about 2 times higher than that for 37-element NU fuel, because of the higher burnup. In a preliminary fuel channel analysis for 35 % reactor inlet header (RIH) break in CANDU-6 reactor with the CANFLEX-RU, the maximum fuel centreline and sheath temperatures are resulted to be lower by 338 ^{O}C and 122^{O}C, respectively, than those for the existing 37-element natural uranium fuel. The fuel channel integrity shows to be negligibly affected by the axial power distribution shape change of the CANFLEX-RU bundle's channel following the bundle refuelling scheme change.

4. AVAILABILITY AND PROCESSING OF RU

The cumulative quantity of RU projected to arise from the reprocessing of European and Japanese spent fuel by 2000 is approaching 25,000 te [6]. This RU, which is owned by the utilities or reprocessors, is an alternative fuel source to new natural uranium for use in LWR and CANDU reactors. Each country and utility will determine its strategy for RU based upon local factors. Theoretically this 25,000 te would provide sufficient fuel for 500 CANDU-6 reactor years operation, since the initial core load of uranium for a CANDU-6 reactor is 85 t, and annual refuelling requirements for a RU fuel burnup of 13 MWd/kgU are around 50 t/a.

Current reprocessing technology has been optimised to produce an RU product suitable for interim storage pending re-enrichment and recycle into LWR reactors. BNFL uses thermal denitration to convert UNL (Uranyl Nitrate Liquor) to UO_3. COGEMA uses the ADU route to convert UNL to U_3O_8. Further processing would be required to convert this to sinterable powder. Several processes exist to convert the RU from its form used in storage, to ceramic grade sinterable powder. For example the UO_3 from BNFL's THORP reprocessing plant could be further processed to UF_6 and the existing IDR (Integrated Dry Route) facilities used to convert the UF6 to ceramic grade UO_2. Alternatively, BNFL has a prototype facility in operation, which converts the UNL directly to a ceramic grade UO_3 (subsequently to UO_2) by the MDR (Modified Direct Route) process. This route offers significant savings in the longer term if sufficient CANDU RU demand develops.

5. FABRICATION AND HANDLING OF RU CANDU FUEL

The isotopic composition and activity of un-enriched recovered $U0_2$ powders depend inter alia on the reactor type, initial enrichment and discharge burnup of the PWR fuel, the time between spent fuel discharge and reprocessing, the route chosen to convert the UNL to UO_2, and the delay until fuel fabrication. RU contains typically ~1 ppb ^{232}U which decays with a half-life of 69.8 years. The daughters in the ^{232}U decay chain are removed during reprocessing but grow during storage. Conversion processes via UF_6 also remove daughter products. The first daughter in the chain is ^{228}Th with a half-life of 1.9 years. Since all the other daughters in the chain have much shorter half-lives, including the radiologically important ^{208}Tl and ^{212}Bi, they are all in secular equilibrium with ^{228}Th. Therefore, the ^{228}Th build-up governs the rate of build-up of gamma activity and indicates the gamma activity with time relative to the quasi-equilibrium level attained after about 10 years. RU also contains ^{234}U that contributes to a higher specific alpha activity compared to NU. However, the level is about the same as in conventional enriched PWR fuel, since the source of the increased ^{234}U is the initial enrichment of NU. RU also contains trace fission product gamma and beta emitters, and transuranic alpha emitters.

An initial assessment of the health physics aspects of manufacturing and handling RU as a reactor fuel for CANDU was done in the joint program between BNFL, KAERI and AECL, and before that in a joint program between AECL and COGEMA [6]. BNFL has converted reprocessed spent PWR fuel into 200 kg of $U0_2$. The characteristics of the recovered $U0_2$ powder met CANDU specifications, both in terms of chemical impurity contents and physical characteristics. The powder was granulated and pressed into green pellets, which were sintered under the normal conditions for CANDU fuel. The finished pellets met all the physical and chemical specifications for CANDU fuel.

The conversion took place one year after reprocessing. Activity level measurements made on the finished CANFLEX-RU bundle were 1.3 times higher than a natural uranium bundle, when measured at 30 cm distance. This CANFLEX-RU bundle was displayed at AECL's Sheridan Park Engineering Laboratories (SPEL) during the 5th International Conference on CANDU Fuel, 1997 September 21-25, in Toronto, Canada, where delegates were able to see and handle both RU and natural uranium bundles. Consequently, because the total fuel quantity required can be reduced by around 50% using RU, the overall dose uptake to the workforce during the fabrication and handling of RU bundles will be comparable with that presently seen for natural uranium fuel. By reducing the time from reprocessing to conversion, fuel fabrication, and insertion into the reactor, the dose uptake will be reduced even further.

During the sintering, the release of ^{137}Cs and other volatile fission products from RU was below detectable levels. Also, AECL[6] earlier concluded that no significant fields in a commercial fuel fabrication plant would build up due to release of ^{137}Cs during sintering, even after decades of production.

7. FUEL CYCLE COSTS FOR RU

Most countries and/or utilities, which adopt a reprocessing strategy, do so for strategic energy self-reliance and/or for waste management reasons. Generally, RU is owned by the utility that contracts for reprocessing of spent uranium oxide fuel. The uranium and plutonium recovered from reprocessing are often held as "low or zero cost" stocks by the utilities. Hence, there is the possibility that RU will be competitively available on the open market.

The potential annual saving to a CANDU utility by the utilisation of RU is significant, but strongly dependent on the price paid for the RU powder and fuel fabrication.

The costs of the front-end of the fuel cycle (excluding back-end storage and disposal costs) in US dollars were assessed for RU in CANDU and re-enriched RU in a PWR by Boczar et al.[7], for a range of RU-cost assumptions. This parametric survey indicated that, with RU at no cost, CANDU fuelling cost with RU is >70% lower than for re-enriched RU in PWR. With RU at no cost, the CANDU fuelling cost is reduced relative to NU fuelling by 45% with NU at 25 $/kgU, and by 67 % with NU at 80 $/kgU. With RU at NU cost, the fuelling cost savings in CANDU with RU are 28 % for NU at 25 $/kgU, and 34% for NU at 80 $/kgU. With RU at NU cost, the fuelling costs are 10 - 15 % lower than for 1.2 % slightly enriched uranium (SEU), which is the economic optimum SEU enrichment.

KAERI also assessed relative annual savings of CANFLEX-RU to existing 37-element NU fuel bundles in CANDU-6 by assuming that the fabrication cost of the RU fuel bundle is about 16 % higher than that of the 37-element bundle. With recycled UO_2 priced at 25 % of the natural UO_2 price, the annual fuelling costs will represent a 64 % saving relative to that of NU in 37-element bundles. Similarly with recycled UO_2 priced at 124 % of the natural UO_2 cost, the annual fuelling cost of the RU fuel bundles would show a saving of 31 % relative to that of the 37-element bundles. Break-even between RU and NU UO_2 is represented with recycled UO_2 priced at 210 % of the natural UO_2 price.

Ongoing work will reduce the uncertainties in the fuelling costs for RU, namely the cost of ceramic-grade UO_2 powder, and the cost of CANFLEX-RU fuel fabrication. Finally, another AECL paper [11] quantifies significant cost savings in the back-end of the fuel cycle with SEU (or RU).

8. CONCLUSIONS

Korea can exploit the natural synergism between the two reactor types of PWR and CANDU reactors to minimise overall waste production, and maximise energy derived from the fuel, by recycling the spent fuel from its PWR reactors in CANDU reactors. As one of the possible fuel cycles, RU fuel is a very attractive alternative to the use of NU and SEU in CANDU reactors, offering among other benefits, the advantage of potentially lower fuelling costs. The RU fuel development program and international collaboration between AECL, KAERI and BNFL is a part of KAERI's comprehensive development program of CANDU advanced fuel and includes a clear vision of how the product will evolve over the next 10 years. The key targets of the program are safety and economic enhancements, and reduction of spent fuel volume, using the inherent characteristics and advantages of CANDU technology.

RU is one of the products from conventional reprocessing of spent uranium oxide fuel and typically will have an overall nominal ^{235}U content of 0.9 %. The composition of un-enriched RU depends on the reactor type, initial enrichment and discharge burnup of the PWR fuel, the time between spent PWR fuel discharge and reprocessing, the route chosen to convert the UNL to UO2, and the delay until fuel fabrication. It is only slightly more radioactive than NU. The RU can be used directly in CANDU reactors. A number of options exist for the conversion of the UNL to ceramic-grade UO_2, including direct conversion using MDR and ADU processes, or fluorination to UF6, followed by the IDR route. The RU available to utilities and reprocessors in Europe and Japan by 2000 cumulatively is expected to be approaching 25,000 te. This quantity of RU, if used solely for recycle in CANDU reactors, would provide sufficient fuel for some 500 CANDU-6 reactor-years of operation, since the initial core load of uranium for a CANDU-6 reactor is 85 t, and annual refuelling requirements for RU with burnup of 13 MWd/kgU are ~ 50 t/a. Security of supply is not an issue, since SEU could be substituted for RU. The suitability of RU as a reactor fuel for CANDU has been shown: CANDU fuel fabricated from RU meets CANDU specifications; RU does not pose serious radiological difficulties, and no special precautions or technologies are required for handing RU, because the dose fields associated with RU are just slightly higher than NU; fuel management is particularly simple.

Taking the CANFLEX 43-element CANDU fuel bundle as the carrier of RU fuel, some preliminary evaluations of CANDU reactor physics, thermalhydraulics, safety and fuel performance of CANFLEX-RU indicated that the fuel would not cause excessive channel or regional overpowers, or significant risk of fuel element failure in spite of its higher burnup and slight enrichment relative to natural uranium. However, future detailed analyses of the RU fuel are required to provide a detailed rationale for the justification of the R & D efforts on it for the advanced fuel cycle of CANDU reactors in Korea. The justification includes the licensing issues in the KSRG.

With RU available free-issue, the annual fuelling costs could be reduced by ~ 30 - 60%, compared to NU fuel. With ceramic RU powder at NU cost, the fuelling costs are 10 - 15% lower than for 1.2% SEU, which is the economic optimum SEU enrichment. These cost savings are strongly dependent on the cost of ceramic grade $U0_2$, and the cost of CANFLEX-RU fuel fabrication. Fuel management with RU is considerably simpler than that for 1.2% SEU, and good fuel performance is assured as a result of the lower ratings with CANFLEX. In the current collaborative program between KAERI, AECL and BNFL, RU fuel development and proof testing will be completed by around 2005, and there should be no impediment to the use of RU fuel in the CANDU-6 reactors in Korea, if RU is competitively available.

RU is very attractive option of advanced fuel cycles not only in Korea, but also in World, because the use of RU in nuclear reactors improves uranium utilisation and saves new natural uranium for our second generation.

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