DIRECTION OF REPROCESSING TECHNOLOGY DEVELOPMENT
BASED ON 30 YEARS OPERATION OF TOKAI REPROCESSING PLANT

Nomura S. ¹, Tanaka K.¹ and Ohshima H.²
¹ Tokai Reprocessing Technology Development Center
² Nuclear Fuel Cycle Engineering Laboratories
Japan Atomic Energy Agency, 4-33 Tokai-Mura, Ibaraki, Japan

1. Introduction

Tokai Reprocessing Plant (TRP) of JAEA was designed 1970s to reprocess nuclear spent fuel (NSF) mainly from domestic Light Water Reactors (LWR) and Advanced Thermal Reactor (ATR) ‘Fugen’. It was necessary to challenge many requirements for steady operation of plant due to mechanical troubles in head-end process, acid corrosions of dissolver vessel and evaporator tubes, strict environmental restriction to release activity, and reduction of waste volume. Through these solutions, the maturity of current reprocessing technology was achieved. The next generation reprocessing system for Fast Reactor (FR) cycle will be industrialized by the best combination of innovative technologies from R&D efforts and the supporting technologies obtained by 30 years plant operation experiences.

2. Operation experience of TRP

TRP was designed mainly by the introduction of French SGN technology in 1970s and constructed by the domestic companies. (Fig. 1) It started hot operation in 1977. Records of annual amount reprocessed are shown in Fig. 2 under the licensing restriction of 0.7 tons per day. After 1st scheduled shutdown in 1988-89, steady operation was reached about 90 tons per year. It took 12 years to stabilize the plant operation equipped with the technologies originally developed 1970s, because of many modifications of process condition, replacement of dissolver and evaporators, and addition of waste treatment facilities. French La Hague UP2-400 took for 10 years in 1970s-80s, UP3 for four years in 1989-93, and UP2-800 for only one year in 1994-95 to reach the steady state operation by operation experience feedback.[1] Now, reprocessing with PUREX process reached a mature technology during the last 30 year efforts with continuous improvements of technology and plant operation efficiency.

TRP reprocessed 1,100 tons of NSF UO₂ with 20 tons of ATR-MOX under IAEA full scope safeguards by mid 2006. Recent operations have been adjusted around 30 to 40 tons per year because of collaborative supports of Rokkasho Reprocessing Plant (RRP) of JNFL by 130 engineers and technicians from TRP. In TRP, all Pu recovered of about 7.5 tons has been co-converted for MOX powder and recycled for fuels of FBR ‘MONJU’, ‘JOYO’ and ATR ‘FUGEN’. Total 1,054 tons U was also recovered and provided partly 353 tons for enrichment and direct use for Fugen MOX. It demonstrated an engineering scale Pu-U use in the closed fuel cycle.

Figure1 Tokai Reprocessing Plant
3. Establishment of reprocessing technology for TRP

With 30 years experience of TRP, technologies developed for establishment of LWR reprocessing has been focused in a field of a reliable plant operation, decrease of environmental burden, improved waste treatment, and non-proliferation issues. Major technologies shown in Fig.3 are as follows;

1) Inspection and repair tools
Remote maintenance by inspection and repair tools is a key technology to keep a high efficient operation of the plant. TRP developed such tools and applied to fuel dissolver, evaporator, high active liquid waste storage tank, and so on. When defect of components is detected in-service inspection, in-situ repair is implemented smoothly by these tools.

2) Corrosion free components
TRP stopped the operation in an early stage due to corrosions of welded parts of high Ni-Cr austenitic alloy for spent fuel dissolver and acid recovery evaporator. Components made by refractory alloys of Ti and Ti-5Ta were installed and demonstrated its excellence for more than 30,000 hours. Also ceramics valve was adopted and showed excellent performance under TRP operating condition. These new materials will be applicable to advanced reprocessing facility as a corrosion free component.

3) Vitrification of high-level radioactive liquid waste (HLW)
Achievement of reliable technologies on solidification and disposal of the HLW is one of the most important issues to establish the closed fuel cycle systems. JAEA has been carrying out to accomplish more stable and reliable operation of vitrification process by development efforts to avoid noble metal accumulation. [2]

4) Seismic isolation system
New compact utility building was constructed with seismic isolation system and started to provide electricity, steam, cooling water to TRP from 2004. There installed 32 rubber bearings and 80 lead dampers at the basement. It demonstrated excellent performance by an artificial seismic testing.

5) Co-conversion system by micro-wave direct denitration technology
From 1983 in TRP, Pu solution has been always co-converted with U solution to MOX power by microwave heating method with the capacity of 10 kg (Pu+U) per day for non-proliferation purpose. Total 14.5 tons of homogeneous and stable MOX powder was supplied for the fuels of JAEA reactors. MA containing
MOX powder, which is a candidate of advanced FR cycle, can be manufactured by the same technology. Such powder will be supplied for the short process of MA-MOX pellets fabrication.[3]

6) Safeguards technology
There are many technological advances achieved, such as a near-real time accounting by solution monitor, drum assay system for Pu measurements in a waste, neutron detector for verification, and so on.

Figure 3   Major technologies developed by TRP

4. Goal of closed fuel cycle

There are typical two ways of NSF management; 1) direct disposal as a waste, and 2) reprocessing as a recycle use. Many countries hold over the decision of it by adopting the third option; 3) wait and see. World wide NSF is a huge amount of about 300,000 tons accumulated and the current increase per year is about 10,000 tons from the existing world 440 reactor units. Total amount of NSF reprocessed so far reaches about 30,000 tons. Current maximum reprocessing capacity is about 3,000 tons annually for facilities in France, UK and Japan, which PUREX process has been industrialized for the last 30 years. In an annual global base, NSF of about 7,000 tons cannot be reprocessed. It indicates a lot of interim storage facilities will be needed in a world wide scope.

Reprocessing and recycle policy, which was reconfirmed by the recent Japanese nuclear energy policy, is not a major choice yet in global countries due to economics and nonproliferation issues. However, recent global interest focuses the future possibility of NSF recycling with advanced FR fuel cycle system, which challenges these issues. USA recognizes the total advantages of reprocessing and recycle policy as a GNEP and moves the new closed cycle option with on-going YMP.[4] Especially in the backend cycle, it can be achieved a substantial reduction of area for high level waste disposal, such as 1/4 to 1/5 volume reduction from NSF direct disposal as well as the significant decrease of radioactive toxicity.

Goal of closed fuel cycle is to achieve the maximum use of uranium resources and minimum disposal of waste by multi-recycle of TRU (U, Pu, MA) as a competitive nuclear energy system. (Fig. 4) LWR cycle is not self consistent, because supply and demand of U- Pu is not balanced in the cycle. The saving rate of U
resources for LWR cycle is max 30% compared with LWR once through. FR cycle is self-consistent by multi recycling of TRU with minimizing both U supply and waste disposal. It should be achieved by a high burnup of 150 GWd/t. U and Pu are adjusted flexibly in a cycle by changing a core specification of FR. During the long transition period from LWR to future FR cycle, it is assumed that major NSF will come from LWR interim storage facilities and operating LWRs. NSF from FR will increase gradually up to FR equilibrium cycle era. Therefore, the next generation reprocessing facility will handle NSF from both LWR and FR. TRU products recovered will be recycled preferentially for FR fuels. In this future prospective, safe and reliable technologies should be optimized with economically competitive and proliferation resistant bases.

Figure 4  Goal of fuel cycle (case:1MkWe-year) for max. use & min. waste of U resources by self-consistent FR cycle

To complete TRU multi-closed recycling as a competitive nuclear energy system, reprocessing and fuel fabrication system should be synchronized with the advanced reactor system and the back-end system for waste treatment and disposal. Overall system optimization focusing material follow is most important to complete a closed cycle. Current reprocessing system should be changed to handle TRU with more reductions in a cost and less waste volume, as well as an intrinsic proliferation resistance. There are many advanced flow sheets under development. For the successful industrialization of advanced reprocessing technology, it is necessary to combine three key elements of R&D efforts, engineering base demonstration and experiences of plant operation.

5. Development of advanced reprocessing technologies
TRP completed the service reprocessing of LWR SNF by FY2005, which was contracted with domestic utilities from the beginning of TRP operation. Now, role of commercial reprocessing shifted to RRP from TRP. Midterm plan of TRP in Fig. 5 focuses R&D of advanced reprocessing. The important technical data will be obtained from the reprocessing of 100 tons of MOX spent fuel in FUGEN and high burnup UO2 spent fuel in domestic LWRs. Other research reactor fuels will be reprocessed as a part of decommissioning plan.
Development of core technologies for advanced reprocessing will be also planned as follows; These reprocessing technologies as a basic supporting element can be demonstrated their performance efficiently by using SNF in the actual reprocessing plant. It should be noted that candidate technologies to be developed need the R&D and demonstration in order to get a reliable situation for industrialization.

1) Centrifugal contactor for simplified co-extraction process of Pu-Np-U
When co-extraction of Pu-U-MA is developed in a single aqueous process, it achieves more economical and proliferation resistant situation of advanced reprocessing by a drastic size reduction of facility and related utilities. Centrifugal contactor, which major countries have been developed as a next generation key machine for extraction in stead of pulsed columns, provides a lot of advantages; compact, rapid extraction and separation, easy start-up and shut-down operation. (Fig. 6) In JAEA, multistage system of centrifugal contactor is in the stage of demonstration for FBR fuel reprocessing.  

2) Advanced vitrification technology
The current vitrification technology is expected to apply the solidification process of the HLW generated from future fuel cycle systems with some modification and optimization of the melting condition. The advance aqueous reprocessing system itself has the potential which contribute to the further reducing the number/volume of the HLW with combining separation technology of TRU and LLFP elements.
3) Advanced safeguards
Advanced reprocessing and fuel fabrication facilities can evaluate the measures and lessons from TRP operational and implementation experiences under IAEA full scope safeguards. Development of remote, real time and accurate in-situ monitoring technologies becomes a powerful tool for advanced safeguards system. Advanced chemical analysis for TRU elements, especially Np, Am are also important for it.

4) Application of new technologies
There are many innovative new technologies outside a nuclear. These are robotics, micro beam-imaging technologies, radiation proof parts, new materials, biochemistry, and so on. It can be introduced to key components, process management, inspection-repair machines, and waste treatment for the advanced fuel cycle facilities.

6. Conclusion

It needs wide technologies to implement design, construction and operation of reprocessing facility. Technology and experience feedbacks from the last 30 years operation of TRP are important to realize a reliable, effective, and economical advanced reprocessing plant, such as FR cycle demonstration plant and 2nd reprocessing plant in Japan, Advanced Fuel Cycle Facility of GNEP. Supporting technologies should be matured to keep the scheduled annual throughput by reprocessing of NSF and supply of fuel product without any interruptions of the plant. There are many supporting technologies developed or modified in TRP; such as components of corrosion resistant material, radioactive chemical analysis, plant control system, aqueous solution chemistry & physics, maintenance tools, quality assurance system, safeguards system, and others.

For the advanced reprocessing plant, these technologies should be maintained and transferred to the next generation with the technical support of JNFL-RRP. Establishment of knowledge management and breeding of specialist are one of main issues to succeed it.

7. References
[2] M. Shiotzuki, A. Aoshima, S. Nomura, “Perspectives on application and flexibility of LWR vitrification technology for high level waste generated from future fuel cycle system” WM06 March 2, Tucson