TECHNICAL SESSION I – SUMMARY
Fuel Cycle Strategy and Future Reactors

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Papers presented:

National and international policy papers (Korea, IAEA)	2
Overviews of R&D programmes (Czech Republic, FZK)	2
Phase-out study	1
Fuel cycle schemes (ORIENT cycle, Double Strata, CORAIL, PEACER)	4
TRU burners (Core design and optimisation)	2
Molten-salt transmuter	1
Thorium-based systems (Thorium-based LWRs, generic study)	2
Fission product transmutation	1
Total	**15**

Role of P&T on permanent disposal of HLW in Korea

Y-S. Hwang and J-H. Park (KAERI, Korea)

To increase the capacity of the currently considered repository, i.e. a repository for the direct disposal of the spent fuel arising from 28 operating or retired reactors by 2015, Korea develops the metallisation process by lithium reduction.

The concept allows to separate FPs with high decay heat (^{90}Sr and ^{137}Cs), which go to the salt, from the other FPs and the TRU, which form a metal ingot. The solidified salt is stored above ground until most of the activity is decayed; the metal ingot goes to HLW.

The paper describes the process and presents thermal analysis and nuclide transport results. The repository volume reduction is estimated to be 60% relative to the direct disposal concept.

It is not yet decided whether or not the process will ultimately be combined with a transmutation system.

Long-term issues associated with spent nuclear power fuel management options
J-S. Lee et al. (IAEA)

Reviews the status and trends for spent fuel management options with regard to country-dependent preferences. Notable points are:

- Today, the bulk of the spent fuel in the world is in storage. Interim storage, dry for the longer term, allows to adopt a "wait for better solution" policy based on P&T and other sustainable technologies as discussed e.g. in the Gen IV and INPRO projects.
- Non-proliferation and the limited attractiveness of single-recycle strategies have motivated countries to move from reprocessing to direct disposal strategies. However, only a few disposal projects have been finally endorsed.
- For economic reasons, the launching of P&T and similar options will depend on an increase in the future nuclear energy demand.
- Interest in regional/international co-operation may be revived.

Current status of Czech R&D programme in partitioning and transmutation
J. Uhlíř et al. (NRI Rez, Czech Republic)

In the Czech Republic, the transmutation of spent fuel from LWRs is considered as a prospective alternative to the direct disposal of the fuel. At NRI Rez, the respective R&D is focused on molten-salt transmuters using fluoride-salt based liquid fuel and pyrochemical/pyrometallurgical fluoride partitioning for the spent fuel.

Particular areas of research comprise:

- Technological research on the "fluoride volatility method" and laboratory research on electroseparation methods.
- Development of static and transient computer codes for the neutronic analysis of liquid-fuelled systems.
- Reactor physics experiments at the VR-1 and LVR-15 facilities.

The activities are embedded in EC research projects.

Overview of the P&T activities at Forschungszentrum Karlsruhe

J.U. Knebel (FZK, Germany)

Overviews the long-term perspectives of the nuclear safety research programme at FZK with emphasis on P&T activities and reports recent technological achievements in the Karlsruhe Lead Laboratory KALLA. The activities comprise:

- Feasibility, design and scenario studies on systems with and without ADS (neutronics, thermalhydraulics, materials, safety).
- Development and study of efficient separation processes.
- Studies on heavy liquid metal technologies and related phenomena in KALLA (thermalhydraulic phenomena, corrosion and oxygen control in liquid Pb-Bi, measurement techniques).
- Participation in international projects (MEGAPIE and TRADE).

The activities are embedded in EC research projects and contribute to the network ADOPT which supports the development of a European ADS demonstrator.

Transmutation capability of once-through critical or sub-critical molten-salt reactors

E. Rodriguez-Vieitez et al. (UCB, USA)

Reports results of a parameter study for a graphite-moderated, molten-salt fuelled TRU burner as originally proposed by Bowman.

The variables of interest are the pitch and the diameter of the fuel channels, the feed and removal rate of the liquid fuel, and the actinide concentration in the feed. The results pertain to the optimisation of the fuel channel parameters while the other parameters are kept constant.

Under the assumptions made, important conclusions are:

- The k_{eff} peaks in the C/MS range 1 to 5 and can achieve the critical value (implies operation with an epithermal spectrum).
- For C/MS=1, the "fractional transmutation" exceeds 90%, the equilibrium actinide concentration is at a minimum and well below the solubility limit.

Detailed phase-out TRU transmutation scenarios studies based on fast neutron ADS systems
E. González et al. (CIEMAT, Spain)

Addresses the issue of the remaining fuel inventory when a reactor park is closed down.

CIEMAT has analysed the different phases of a transient LWR-ADS scenario, where the LWRs produce 100 t of TRU over a 50 year time period. The ADS is a fast spectrum, alloy-cooled system with fertile-free fuel.

It is shown that the chosen type of ADS can be used throughout the scenario, but the core has to be re-optimised to account for changes in the fuel composition.

The phase-out takes 140 to 180 years, i.e. 3 times as long as the production period of the LWR.

The evolution of the installed power, the fuel composition, the required reprocessing capacity, and the fuel losses to the repository are evaluated.

"ORIENT-CYCLE" – An evolutional recycle concept with fast reactor for minimising high-level waste
N. Takaki et al. (JNC, Japan)

Proposes an all-FR system with fully closed fuel cycle and "rough removal of unnecessary material". The following categories of unnecessary material are considered:

- Cs, Sr (heat producers); they are stored until they are decayed.
- Non-radioactive FPs (60%), including strong neutron absorbers; they go to a repository for stable or low-level waste.
- LLFPs: they go to HLW (iodine is transmuted in the FRs).

The HLW can thus be reduced by an order of magnitude.

The special aqueous separation processes are described, and the neutronic feasibiliy of the multiple fuel recycling is analysed.

Analysis of mass flow and cost for double-strata fuel cycle

K. Nishihara et al. (JAERI, Japan)

Presents mass flows and electricity generation costs for six "fuel cycle schemes", i.e. the LWR once-through cycle, FRs with fully closed fuel cycles, and four double strata schemes. The latter are based on the following conventional reactors: normal LWRs, LWRs with a single MOX recycle, RMWRs with multiple Pu recycle, and FR-MOX reactors. The cost data base is mostly that of the recent NEA study "ADS and FR in Advanced Nuclear Fuel Cycles".

Result

- Comparing the double strata schemes, the LWR-based scheme features the highest cost and the FR-based scheme features the lowest cost.
- Higher mass flows to the 2^{nd} stratum imply higher generation costs, but the RMWR-based scheme is also penalised by a large amount of reprocessing.
- The pure FR scheme and the FR-based double strata scheme feature similar costs which appear to be ~25% above those of the current LWR once-through cycle.

An investigation of TRU recycling with various neutron spectrums

Y-N. Kim et al. (Hanyang University, Korea)

Investigates the influence of the neutron spectrum on the burning of the non-fissile TRU species and important core safety parameters (fuel Doppler, kinetic parameters) using HYPER as the reference system.

Conclusions

A reduction in core size "hardens" the neutron spectrum and hence improves the burning of the non-fissile TRU species (especially for ^{240}Pu), but leads to a deterioration of the core safety characteristics.

→ Trade-offs are necessary.

Saturation condition and evolution of the nuclides for sub-critical system driven by accelerator

S. Fan et al. (CIAE, China)

Reports results of a generic study aimed at investigating the evolution and equilibrium concentration of actinides in different materials (natural U, ^{232}Th, ^{232}Th-^{233}U mixtures) under neutron irradiation.

The neutron spectrum and the flux are considered as parameters.

Fully homogeneous calculations are carried out using a simplified burn-up algorithm. Based on the results, optimum parameters for different applications are recommended.

Transmutation of long-lived fission products in a sodium-cooled ATW system

Y. Kim, R.N. Hill, W-S. Yang and H. Khalil (ANL, USA)

Presents results of a design optimisation study for the transmutation of ^{99}Tc and ^{129}I in a sodium-cooled ATW system.

FP targets from metallic Tc and CaI_2, placed in ZrH_2-moderated assemblies, as well as homogeneous concepts are investigated.

Spectral sensitivity studies, followed by full core depletion calculations, were carried out to find optimum target assembly designs and target loading options.

Notable conclusions are:

- A heterogeneous loading enables higher FP burn-ups.
- Target assemblies are preferably loaded at the core periphery.
- A 1:1 ratio for the Tc and iodine assemblies is compatible with the FP ratio in the spent fuel.
- With a 5 year irradiation, consumption fractions of ~29% (Tc) and ~37% (iodine) can be achieved.
- All together 24 target assemblies can be loaded at the cost of a 10% increase in fuel inventory.

Partitioning and transmutation of spent nuclear fuel by PEACER
B-G. Park et al. (SNU, Korea)

Reports the development status of the PEACER concept which combines LWRs with critical Pb-Bi cooled TRU burners using an IFR-type fuel cycle.

^{99}Tc and ^{129}I are transmuted in a thermal neutron trap located between the fuel and the top reflector zone of the core.

A PEACER plant consists of four 550 MWe transmuters and two reprocessing units, each with a throughput of 322 t/a. Only pyrochemical processes are used, and these are designed to produce practically no HLW.

The concept has been optimised for a good support ratio (LWR-to-FR electric ratio = 2), favourable reactor safety characteristics (hypothetical core accidents have also been analysed), and good proliferation resistance (low content of Pu in fissile isotopes).

A preliminary assessment of the waste volumes has also been made.

PWR-to-accelerator-driven system (ADS) fuel cycle employing dry process
M. Iqbal, C-J. Jeong and G-H. Roh (KAERI, Korea)

Describes a Monte Carlo burn-up analysis of a Pb-Bi cooled ADS core which is designed to burn complete spent fuel from PWRs.

For non-proliferation reasons, only an oxide-to-metal reduction, but no separation process is employed. To achieve a k_{eff} of 0.97 at BOL, a similar amount of 20% enriched uranium driver fuel is loaded into the core.

Results

- The time evolution of the reactivity, the power distribution and neutron spectra are given.
- During the one-year cycle, the accelerator power increases by a factor of 3, but this could be reduced by an appropriate fuel shuffling.

Assessment of the equilibrium state in reactor-based plutonium or transuranics multi-recycling
T-K. Kim et al. (ANL, USA)

Investigates the equilibrium state of CORAIL and other special fuel assemblies for the multi-recycling of Pu or TRU in PWRs using a special equilibrium searching algorithm.

Conclusions

- Indices for full-MOX and multi-recycled CORAIL assemblies are roughly similar.
- Additional MA recycling reduces waste radiotoxicity significantly, but leads to very high decay heat and neutron source strength levels of the fuel.
  → Further studies needed to determine practical number of recycles.

Use of thorium for transmutation of plutonium and minor actinides in PWRs
E. Shwageraus et al. (MIT, USA)

Reports results of a parameter study aimed at the investigation of Pu and MA destruction rates in Th-based PWR fuel. The analysis is performed at the pin-cell level, using the CASMO4 code.

Regarding TRU destruction, important conclusions are:

- Destruction rates of ~1 000 kg/GWe-a and residual TRU fractions of ~50% per fuel pass are reasonably achievable for optimised, denatured fuel elements. However, the TRU destruction arises mainly from the burning of Pu.
- To achieve these values, the H/HM ratio has to be increased with respect to that of a normal PWR. This is also beneficial from the reactivity coefficient and reactivity control viewpoints.