Summary of Session 1: Concepts of Accelerator-Based Transmutation Systems

H. Rief

In the first session of the meeting concepts of accelerator-based transmutation systems aiming at the transmutation of actinides and long-lived fission products were reviewed. As already described at earlier occasions, the transmutation process is either based on fast or thermal neutrons generated in accelerator-driven subcritical systems.

Both type of systems claim specific merits. While for fast neutron systems the better fission properties of actinides are put in evidence, supporters of thermal systems advertise the advantages of a small fissile material inventory. In both cases those options which work with continuous reprocessing and a closed fuel cycle avoiding solid (actinide) fuel fabrication are considered to offer great advantages.

Substantial modifications of the concepts proposed previously could be noticed leading to the conlusion that the search for optimized solutions is still going on. For the LANL project, which has kept its pace-maker role, a new solid tungsten target and actinide slurry-bearing pressure tubes were proposed and analysed.

Summary of Session 2 (Part 1): Nuclear Design Problems of Accelerator-Based Transmutation Systems with Emphasis on Target Facilities and their Interfaces with Accelerators

T. Takizuka

- Topics Presented

Various concepts were presented and the relevant problems were discussed

- Solid target/fuel, fast flux system concept.
  Engineering design problems.
- Molten-salt target/fuel, fast flux system concept.
- Thermal flux system, solid target/fluid blanket concept.
- Thermal flux system, effect of flux level.
- Criterion and requirements to the transmutation.
- Thermal flux system, blanket design schemes.

- Conclusions

- All the concepts presented in the first part of Session 2 are based on the combination of intense proton accelerator and spallation target/subcritical blanket.
- These concepts follow two approaches; some use fast flux while others use thermal flux. Each approach has its advantages and disadvantages.
- A variety of design schemes were presented.
- Many design problems were identified.
- An important problem is that design data with sufficient accuracy are unavailable.
- It seems to be premature to evaluate the proposed systems quantitatively.

- Recommendations for Future Work

- Further improvements of data and methods are strongly recommended.
- Further studies are required to detail and optimize the engineering designs.
- It is recommended to identify priority technical problems and to evaluate the required accuracy of data and methods.

Summary of Session 2 (Part 2): Nuclear Design Problems of Accelerator-Based Transmutation Systems with Emphasis on Target Facilities and their Interfaces with Accelerators

H. Takahashi

A study of the reduction of toxicity (hazard) using high intensity thermal and fast neutron flux suggested that irradiation with a low level neutron flux like LW'R below 30 years increases the toxicity compared with the non irradiated one. The high intensity neutron flux is required to reduce toxicity.

Transmutation of fission products type I (Sr-90 and Cs- 137) using thermal neutron capture requires a very high neutron flux because of its very small cross-section. Several alternative approaches were discussed in the context of energy balance; using the 14 MeV neutrons produced by inertial fusion, muon-catalyzed fusion, and also a transmutation approach using a moving target. Although the energy balance is favorable when 14 MeV neutrons are used, the engineering problems involved in implementing this approach require further study.

Before visiting the PSI muon experimental facility, the physics and experimental status of the muon-catalyzed fusion was presented by C. Petitjean who is in charge of the international collaboration carried out there. The possibility of creating 10^{17}n/cm^2 /see neutron flux using muon-catalyzed fusion reaction was discussed.

Summary:

For shortening the decay process (weak interaction) of nuclei we are dealing with transmutation (strong interaction) by injecting medium energy protons accelerated by electromagnetic force. By including in our consideration the isolation of FPs into outer space or in the antarctic ice field (gravity), me might be able to find ways to solve the problem of high-level radioactive waste using a suitable combination of these four forces in the same way as Einstein, who discovered the theory of relativity, tried to unify the electromagnetic and gravity interactions more than half a century ago. Now, at PSI, the search for the Higgs boson to unify the four forces is being carried out by experiments on muon decay.

Summary of Session 3: Data and Methods for Nuclear Design of Accelerator-Based Transmutation Systems

F. Atchison

The purpose of the session was to identify important gaps in data and/or calculational methods for studies of accelerator-based waste transmutation systems.

The session consisted of an overview and three contributed papers:

(i) a review of the calculational methods available in the G.U.S. presented by L.V. Tochenyi (RDIPE, Moscow)

(ii) calculational results examining the effect of high-energy proton bombardment of minor-actinides in terms of long term toxicity, presented by H.-U. Wenger (PSI, Switzerland)

(iii) the results of calculations looking at the effect of parameter selection on the mass distribution in high-energy particle induced fission, presented by T. Nishida (JAERI, Japan).

The session was followed by a discussion chaired by H. Küsters (KFK, Karlsruhe) on the needs for, and aims of, a task-force to consider the quality of calculational methods for the study of accelerator-based waste transmutation concepts.

The session overran its allotted time due to a gratifyingly large amount of discussion. The general conclusions of session 3 are as follows:-

1. "HETC-style" packages seem to do an adequate job for calculations of the parameters essential for the engineering design of such systems (heating, activation, etc). Such packages are modular and divide the physics into three parts, high-energy transport, fast neutron transport and gamma transport. This separation is desirable so that the relative importance and the essential calculational differences of these various contributions are kept well in mind.

   - High-energy transport will have to rely heavily on theory. There are only three codes available, HETC (Bertini), VEGAS/ISABEL or Barashenkov (DUBNA).
   - Neutron transport in the region below 20 MeV may be carried out on the basis of measured cross-section data by a variety of methods (Monte-Carlo, Discrete-Ordinates, etc) and each represented by several different codes. The major considerations in the choice are (i) interfacing with the neutron-source as produced by the high-energy code and (ii) the need for representing quite complex geometries.
   - Gamma transport may be carried out with standard Monte-Carlo shower codes (EGS, Gèant, etc), coupled neutron/gamma codes or by more straight-forward point-kernal integration methods.

- Comparison of predictions with reality is desirable in an attempt to try and quantify the actual accuracy of the results. Currently operating spallation neutron sources could provide this.

2. The major requirement of calculations for assessment of waste transmutation schemes is that they make ‘sufficiently accurate’ prediction of nuclide inventories, where ‘sufficiently accurate’ means good enough to allow a *fair* comparison of feasible waste transmutation strategies. Any calculational programme would be supported by experiment. Experimental measurements of high energy particle produced nuclide distributions are difficult (and probably expensive) to perform. The codes should be able to help in the design of meaningful experiments (as well as predicting the results!).

   - Several activation build-up-and-decay codes are available but the nuclide data libraries may need ‘quality control’ and/or extension to handle the wide mass distributions resulting from high-energy particle induced reactions. Some work may be required to treat simultaneous bum-up of the produced nuclides in the case of high-intensity, high-energy bombardment.
   - The following problem areas are recognised
     (a) High energy particle induced fission. The current models treat fission as a competitor to evaporation and lead to mass distributions which reproduce, at least qualitatively, details of measured results. The major open questions are (i) the choice of fission probabilities in the fission-transition region (Z from about 84 to 89), which also has a large influence on the mass distribution for the spallation products, and (ii) the choice of post-scission parameters, principally the positions and widths of the charge and mass distributions.
     (b) The energy region 20 to about 100 MeV (the transition between the upper limit of ‘normal’ cross-section data sets and the region where the assumptions of the Serber model are fully satisfied) is not well treated by the current intranuclear cascade evaporation model. This was also discussed in session 4 where it was pointed out that pre-equilibrium models seem to improve predictions for this energy region.

3. HETC, in particular, is no longer one code but exists in several locally modified forms. Something needs to be done to reconcile the “physics” differences (this mainly concerns the fission model, evaporation treatment and the need (or not) to include pre-equilibrium emission). It is the writer’s opinion that the selection of non-essential (*to the physics)* features (input/output presentation, geometry packages, etc) should remain the privilege of the specific user(s).

   The first work of a task-force would be to calculate the same system with these various versions (and any other suitable code package) and see how they inter-compare.

To summarise the summary: We can calculate all required parameters for the design of accelerator-based transmutation systems. The question to be answered is:

Are the results accurate enough?

Summary of Session 4
Related Cross Section Measurements and Integral Validation Experiments

S. Cierjacks

I. General Data Needs

Important needs, the present status of and current activities on measurements, evaluations and compilations of nuclear data for transmutation were presented, and the related problems were discussed.

- Total and differential cross sections for medium-energy proton reactions (mainly spallation and fission) on potential spallation target materials.
- Neutron- and γ-transport cross sections for all important target, blanket and structural materials (all data needed for adequate calculations of scattering, absorption and self-shielding).
- Cross sections for all important transmutation reactions depending on the transmuter concept: (a) Medium-energy proton-, neutron- and light-ion reactions (b) Reactions with neutrons from a fast-system type of field (c) Reactions with neutrons from a thermal-system type of field.
- Displacement and gas production cross sections for low and medium-energy neutrons, light- and heavy ions produced during the intranuclear cascade. Energy- and angular dependence should be sufficient for particles built-up in the target and penetrating the surface of massive spallation targets.

II. Conclusions:

- Even though not yet well specified in detail, accelerator-based transmutation technology requires a large number of special nuclear data not – or not accurately enough – available from previous work.
- A large amount of data needed is already available from previous fission- and fusion-reactor work (especially for neutrons with $E_n \leq 20$ MeV). Above that energy much information has been gathered also from previous cosmogonic, space-research and spallation-source investigations. But the whole data base is by far not complete and sometimes still discrepant.
- For some of the present concepts several key-data are urgently needed; the corresponding data have been identified in preparation and in due course of this Meeting (see Annex).
- Many of the still lacking data can certainly not be measured with the present capabilities of facilities and manpower. Therefore, calculations with suitably validated nuclear model codes are necessary.
- This Specialists' Meeting was considered to be a suitable forum to further future activities on differential and integral measurements, and code developments needed for the special field of radwaste transmutation.

III. Recommendations for Future Work

- Production of CINDA-type indexes to literature and computer files on microscopic and integral data for accelerator-driven transmutation technology.
- Gathering of the extensive information, now available or to become available, from operating spallation neutron sources.
- Performance of special sensitivity studies to identify critical and system-driving data uncertainties and lacking data.
- Initiation of limited evaluations of the important discrepant microscopic data and integral benchmark experiments.
- OECD/NEA encouragement of already existing national and regional activities on compilations (NNDC), evaluations (ANL) and data testing projects (IAEA).
- Further arrangements for interlaboratory activities and international collaboration on data compilations, measurements and calculations as well as data testing.

ANNEX: Urgent Critical Nuclear Data

As a result of the discussions and arrangements of the Meeting, important critical nuclear data, that are urgently needed for the judgement of system-immanent characteristics, were identified.

- Total neutron yields surface spectra and angular distributions obtained from the bombardment of thick targets (U, Pb, Ta, W, Fe, Al) by intermediate-energy protons at a few energies (e.g. 0.6, 0.8, 1.0, 1.5 and 2.0 GeV).
- Double-differential neutron and proton production cross sections on the above thin target materials and for the above proton energies. (Comparison of thick and thin target results: Do errors occasionally compensate in thick target systems, only?)
- Isotope production rates versus mass of spallation and fission products for medium energy protons injected into the important actinide nuclei of rad-waste. (For a better judgement on transmutation systems burning the waste in the spallation target).
- Displacement and gas production cross sections for radiation-resistant ferritic steels. (Both need to be correlated to the relevant mechanical and thermal properties of the material. Life-time of the spallation target container and other nearby structural materials is a severe problem!).
- Neutron and light charged-particle activation cross sections for all target blanket and structural materials for energies up to 1.5 GeV. Most urgent are data for radionuclide production that are important in determining the overall mass balance of a transmutation system (i.e. the ratio of waste material transmuted to radioactive material (chemical or nuclear) created.

- Portion of delayed neutrons (β-values and related spectra) from minor actinides (including Np-237); differential fission cross sections are also desirable.
- Neutron reaction cross sections on ^{238}Np, ^{137}Cs and possibly other short-lived actinides or radioactive fission products, for which significant and system-driving uncertainties now exist.