Presentation by Dr. Koch

After reviewing the outcome of a Workshop on Partitioning and Actinide Transmutation(l), of which the Recommendations are attached, Dr. Koch expressed the willingness of his Institute to cooperate with others by preparing and analysing targets. He stressed the need to avoid duplication of effort and invite the IAEA and NEA to respond to this point. Mr. Crijns said that in principle the IAEA was prepared to support cooperation and, subject to budgetary limitations, could call meetings of experts to decide on further work. Mr. Stevens said that the current NEA involvement was limited to organizing the Information Exchange Programme. This did not extend to organizing additional specialist workshops but there was no reason why the NEA should not help others in organizing such meetings.

(1) EUR 13347en (1991), L.Koch and R. Wellum, editors

RECOMMENDATIONS

General remarks

The participants of the Workshop, conscious of apparent gaps in the present state of knowledge in *the* field, recommend the following studies should be undertaker

1. A task force should be set up to discuss the utilisation of present FR's for the transmutation of minor actinides.
2. A task force should be set up to discuss the technical feasibility of partitioning processes at present under study.
3. Collection of experience in industrial activities of pertinence in designing transmutation schemes.
4. Definition of experimental studies in the field of accelerator spallation of MA's (and f.p.'s).

The participants note that these proposals should not lead to a duplication of similar efforts being carried out by other organisations.

Collaborations should be coordinated within the framework of existing arrangements (e.g. NEA, CEC, IAEA).

Some of the participants indicated their willingness to contribute to the working groups/ task forces and it was agreed that the Institute for Transuranium Elements should organise them. All participants will be contacted so that hopefully the working groups/ task forces can *meet in* the frost half of 1990.

Remarks pertaining to the four sessions

From the presentations and discussions during the sessions, areas of research activities were identified which, in the opinion of the Workshop participants are needed to allow the technical feasibility and potential benefits of the processes to be demonstrated.

1. Nuclear Transmutation Methods for Actinides

Sufficient information exists to conclude that the homogeneous recycle in nuclear power stations is technically feasible. A cost/benefit analysis has been made for the case of oxide-fueled LWR and FR.

The heterogeneous recycle in FR requires further investigations before potential benefits and transmutation costs can be evaluated. This holds also for the special burner reactors, the high flux reactor with art inner thermal region (HFR) and MAB, where in addition irradiation experiments are lacking to prove their technical feasibility. The physical parameters are dependent on the fuel matrix and for nitride and metallic fuels the measurement of integral cross-sections, their verification by irradiation experiments and their incorporation into upgraded simulation codes are necessary for subsequent cost/benefit analyses.

Important issues such as the technological development of high energy proton and electron accelerators and target engineering for them should be priority goals for charged particle transmutation schemes. Furthermore, the upgrade of simulation particle transport codes, the accurate parameterisation of spallation and photonuclear reactions, and irradiation experiments have to be performed for the optimisation and realisation of the schemes. The concept of the fusion burner should be evaluated by suitable irradiation experiments upon availability of a fusion reactor. Then cost/benefit and risk analyses and transmutation costs can be evaluated.

1.1 Fast reactor oxide fuel heterogeneous recycle

1.1.1 Irradiation experiments need to be carried out.

1.1.2 Benefits and preliminary risk assessments to be done.

1.2 Fast reactor, nitride or metal fuel

1.2.1 MA integral neutron cross-sections must be measured.

1.2.2 Irradiation experiments need to be carried out.

1.2.3 Technical feasibility must be demonstrated.

1.2,4 Benefits and preliminary risk assessments to be done.

1.3 High-flux reactor and minor actinide burner

13.1 Technical feasibility must be demonstrated.

1.3.2 Irradiation experiments to be carried out.

1.3.3 Benefits and preliminary risk assessments to be done.

1.4 Accelerators

1.4.1 Irradiation experiments must be carried out.

1.4.2 Technical feasibility must be demonstrated.

1.4,3 Benefits and preliminary risk assessments to be done.

1.4.4 Transmutation costs must be calculated.

1.5 Fusion reactors

1.5.1 Irradiation experiments must be carried out.

1.5.2 Technical feasibility must be demonstrated.

1.5.3 Benefits and preliminary risk assessments to be done.

1.5.4 Transmutation costs must be calculated.

2. Development of Minor-Actinide-Containing Fuels

It has been expressed at the "Second Technical Meeting on the Nuclear Transmutation of Actinides" that there was practically nothing known about minor actinide containing fuels. Since then the gap has almost been closed for oxide fuels. The information has not yet however been evaluated from the point of view of fabrication costs and losses.

No information has been published on minor actinide containing nitride fuels.

Uranium-zirconium based alloys containing low concentrations of fission products have been studied in the context of the Integral Fast Reactor. No information about minor actinide containing alloys has been published. CRIEPI of Japan has began to study this fuel type, which is complemented by contractual experimental research at the European Institute for Transuranium Elements on request by CRIEPI. However, this study is not so advanced that at the present time irradiation behaviour can be predicted.

2.1 Oxide fuels

2.1.1 Fabrication costs and material losses have to be estimated.

2.2 Nitride fuels

2.2.1 Thermodynamic and structural basic data (phase diagrams) are needed.

2.2.2 Technical feasibility must be proved through fuel design aud fabrication.

2.2.3 Fabrication costs and material losses have to be estimated.

2.3 Metallic fuels

2.3.1 Basic data such as phase diagrams are needed.

2.3.2 Technical feasibility of fuel fabrication must be demonstrated.

2.3.3 The behaviour of the fuel material under irradiation must be tested.

2.3.4 Fabrication costs and material losses have to be estimated.

2.4 Targets for accelerators

2.4.1 Specifications need to be defined.

2.4.2 Technical feasibility of fabrication has to be demonstrated.

2.4.3 The behaviour of the fuel material under irradiation must be tested.

2.4.4 Fabrication costs and material losses have to be estimated.

3. Partitioning Processes

The sources of minor and major (Pu) actinides to be partitioned have to be defined before complete partitioning schemes can be worked out.

It is noticeable that of the proposed non-aqueous processes, only two so far are developed. They appear to be complementary. For one of them (lead-glass technique) in which fission products are isolated, the level of information is not sufficient to allow the technical feasibility of the process to be assessed. The separation of actinides from the rare-earths seems technically possible by the second process (electro-refining) but a cost/benefit estimation cannot be made at present.

Several processes to partition rare earths together with minor actinides from HAW have been worked out. However only two aqueous processes which separate the rare earths from the minoractinides have been developed to a semi-technical scale: too little information is available about the carborane process to allow its present capabilities to be assessed; the TALSPEAK process is rather complicated. Further processes such as those based on diamides and higher valencies of Am (and Cm) should be investigated.

The TRUEX process has been developed to the commercial scale and allows major and minoractinides to be separated and concentrated from a wide range of solutions.

3.1 Electrorefining process must be demonstrated with actual HLW and spent MA fuel in order to prove the technical feasibility and to evaluate the potential benefits.

3.2 Basic data are needed for the Pb/glass process to allow the potential of the process to be assessed.

3.3 The technical feasibility of the TRPO process must be demonstrated on a semi-technical scale.

3.4 The technical feasibility of the DIDPA process must be demonstrated on a semi-technical scale.

3.5 The Carborane process has been demonstrated on a semi-technical scale but the technical feasibility of its implementation on plant scale must be shown and the cost/benefits of the implementation estimated.

3.6 Alternative processes for the separation of An from Ln should be developed.

3.7 The TRUEX process has been developed to the point where counter-current testing on a pilot-plant scale on actual HLW is called for.

3.8 Definition of actinide waste sources in processes are needed.

3.9 Separation of MA's using other reagents and methods using higher valence states need to be investigated.

3.10 The problem of ^{14}C in recycling schemes of nitride fuels should be investigated.

4. Nuclear Fuel Recycling Strategies

At the last OECD-organised meeting on recycling scenarios it was agreed that recycling in LWR and FR is technically feasible. However the benefits of doing this were not clear. Since then, some gaps in the knowledge have been filled, but major gaps are still left to be completed before an overview of the subject can be achieved.

The advantages of using hard-flux, fast reactors are evident for most cases, but experimental data on fuel characteristics for such reactors are meagre. Nitride or metal alloy fuels will be suitable in principle and more experimental work is needed to characterise them before a judgement can be made. Thus the technical feasibility and as a result the analysis of possible benefits cannot be made at present.

The situation is worse for recycling schemes using advanced irradiation devices such as spallation reactors or fusion reactors. In these cases, schemes involving them have not yet been proposed in any sort of detail, so an overview is not possible.

4.1 Recyling scenarios using LWR's

4.1.1 **Advanced LWR's should be investigated as part of recycling strategies.**

4.2 Recycling scenarios in fast reactors

4.2.1 **Technical feasibility, benefits and preliminary risk assessments need to be completed for heterogeneous oxide fuel recycling**

4.2.2 **More investigations need to be made into the advantages and disadvantages of the incorporation of nitride or metal fuels into the FR recycle scenarios.**

4.3 Recycling using MAB, SNS, fusion reactors

4.3.1 **Possible fuel cycle scenarios using these specialised devices for MA incineration have to be outlined.**

REVIEW OF SESSION 2

K. EBERT

KERNFORSCHUNGZENTRUM KARLSRUHE, F.R. GERMANY

GENERAL IMPRESSION

OVERVIEWS of Partitioning and Transmutation activities in different countries

- Less skepticism than in the 70s.
- Non-OECD countries become more interested.
- Hope to improve public acceptance.

REMARKS

- Critical evaluation of long-term risks with and without partitioning and transmutation is necessary (Lefèvre).
- Production of secondary waste.
- Fully remote fuel fabrication will be a must. Decentralised reactor and fuel reprocessing and fabrication is not favorable for partitioning and transmutation.
- IFR seems to be "most friendly" for partitioning and transmutation (non-proliferation).

CONCLUSIONS

- It will be a long way to have an industrially feasible(?) partitioning and transmutation system.
- R&D on partitioning and transmutation is very interesting from the scientific point of view and useful for nuclear technology as a whole.
- International cooperation will be very valuable. Increasing activities of NEA and IAEA very welcome and certainly necessary.
- Next meeting, workshop, where, when?

SESSION 2: Heterogeneous: Overview - Data - Partitioning I

DATA BASE

Very valuable and most important to work out the best partitioning and transmutation strategy.

A large number of data necessary:

- generation (Adachi)
- assessment and valuation (Mills)
- availability (Stevens)

WARNING

- Only validated data should be entered into the data bases.
- Experimental check will be a long-term work.
- All parameters of the reactor operation have to be considered (Adachi).
- Only qualified people should use the data and the sophisticated computer codes.
- Physicists and chemists should closely work together in using the data.

PARTITIONING I

- 3 papers dealing with partitioning in connection with present reprocessing technology (aqueous processing).

1. JAERI paper (M. Kubota)

chemistry of separation including experiments with simulated HLW, long-term developments

- rather complicated chemistry
- interesting aspects
- need compaction for industrial application

2. CEA paper (J. Bourges)

reviews 20 years of experience in the field

- showed realistic ways how to attack partitioning
- gave proposals to add new processes to the existing industrial reprocessing technology

3. PNC paper (T. Kawada)

Pilot plant design studies

- comprehensive design
- showed great activity and straight forward policy

SUMMARY

- The aqueous (PUREX) process offers promising possibilities of introducing partitioning of HLW.
- Simplification of reprocessing technology will be very helpful.
- New separation techniques need to be developed (actinides - lanthanides)

Following Professor Ebert's remarks Mr. Stevens wondered whether it was possible to set priorities on the next steps in data collection, whether it was possible to consider designing radiation resistant molecules to improve reprocessing and whether the experience with automated MOX fuel fabrication plants gave confidence for the engineering of plants producing actinide fuels. Professor Ebert believed these topics worthy of consideration for specialist workshops in the not-too-distant future.

Summary of Session 3

by

Dr. Weber (United States)

Dr. Weber briefly reviewed the presentation of Session 3 noting that there were interesting possibilities for research on photochemical partitioning of constituents of process streams and pyrometallurgical processing of spent fuel in fused chloride salts. There was an evident need for further work to reconcile discrepancies in basic physico-chemical data for actinides although for lanthanides the basis seemed to be well established. One of the points emerging from the work on IFR was the importance of waste stream management which could become a fruitful topic for future meetings.

Dr. Horie's approach to treating the high level waste at very high temperature, i.e. boil off volatile constituents, e.g. caesium; separate out the noble metals; and produce a dense final waste form, consisting of the rare earth oxides and remaining fission products, was an interesting alternative approach to glass vitrification or Synroc. This led him to wonder how far it would be possible to extend the capacity of a waste repository by removal of the strontium and caesium fission products thus reducing the heat burden. This strategy would, however, result in a greater quantity of technicium and iodine being put in a repository and they, according to some views, presented the greatest risk to be guarded against.

Dr. Baetsle's presentation had been a useful reminder of the results of earlier work. Dr. Weber said that it was planned to have Oak Ridge Laboratory update an earlier evaluation of the health effects of a once-through as opposed to a reprocessing fuel cycle, taking into account the benefit which accrued from the use of plutonium in reducing mining and other front-end processes. An attempt would be made to compare the IFR with other reprocessing cycles. The work was difficult because of the need to compare near-term with long-term, repository related health effects. In conclusion he said that he looked forward with some trepidation as well as anticipation to the continuation of research on actinides. He noted that it was very difficult to assess changes in public acceptance of a repository with actinide transmutation and such might not occur rapidly.

Summary of Session 4

by

J. Lefèvre (France)

After underlining the salient points of each of the presentations in Session 4, Mr. Lefèvre remarked that he, not a reactor specialist, had been greatly impressed by the volume of work performed on actinide transmutation in reactors. There was a considerable variety of approaches being studied which he found a little surprising in view of the apparently demonstrated preference for using fast reactors. Given the amount of work still needed before any of the technologies could be brought to fruition he wondered whether it was not time to concentrate the effort on a smaller range of options. There should be a role for the NEA in helping to guide the selection of options for further work.

Turning to the future of the Information Exchange Programme he advocated the holding of a number of smaller, specialised meetings before the next general meeting.

Summary of Session 5

by

Dr. L. Koch (CEC)

Dr. Koch observed that the papers had been largely devoted to theory with a model for each occasion although there was no model for all occasions. There was also a scarcity of data for validating models. Some models concerned the use of a sub-critical core attached to the accelerator when the further reactions of fast neutrons led to a net energy balance overall (in this case the major process was fast fission produced by the spallation neutrons). On the other hand Dr. Wydler had presented a concept which had net energy consumption but provided a strong source of neutrons as a by-product. He did not believe this represented a conflict of views.

All the papers seemed to converge on the need for a machine with a beam current at 200mA and 1 GeV. A cost estimate of about $2 billion had been given for such a machine which could cope with an annual throughput of some 200kg of actinides, the output of several LWRS. He wondered whether the cost might be reduced by using cyclotrons, perhaps in tandem.

One paper had considered using a lead/bismuth alloy as cooling medium. This seemed attractive in reducing the chemical hazard but could lead to engineering difficulties in transporting such a heavy coolant. It was evident that novel engineering solutions would be needed anyway for the test facilities which would shortly be built in Japan (BTA in 1992 and an electron accelerator in 1991).

He concluded that while basic data collection and engineering studies were underway there seemed to be a relative absence of work on the fuel cycle. To achieve the required results in reducing toxicities of the waste would need several cycles, as transmutation efficiencies were not high. Recycling might raise additional constraints for fuel and target design. The need to destroy fission products should not be overlooked; reactors did not transmute them so it was to be hoped that accelerators would. A demonstrated ability to do so would enhance the chances of continued funding for research using accelerators. Perhaps one possibility was that a high flux of energetic neutrons produced in the accelerator could be moderated to improve fission product transmutation. This might be a topic for a specialist meeting.

Dr. Wydler agreed with the estimates of neutron fluxes that could be produced by using heavy atom targets and noted that, if the resulting spectrum in a near-critical assembly was similar to that in a reactor, the transmutation performance would be similar. He pointed out that the aim of the case he had presented was to quantify the (high) performance of the pure spallation processes for transmuting actinides. He agreed that if there were a strong neutron flux it would be sensible to consider its use to transmute fission products.

Dr. Takahashi suggested that his rationale for using accelerators with a sub-critical assembly in actinide transmutation might be controversial. He noted that in fast reactors fuelled in part with minor actinides there were relatively few delayed neutrons so that reactor operation became more delicate. Therefore it might be more convenient to use a sub-critical assembly targeted by an accelerator, and perhaps a beam current as low as 5mA would give useful results. This was

unknown and he would try to produce relevant calculations. In regard to fission product incineration he was also thinking of exotic systems, for example, muon catalysed reactions producing 14MeV neutrons might be useful for this purpose even though not for energy production. Another way to produce 14MeV neutrons was the deuteron-deuteron reaction. He had noted recent Russian work in which deuteron-deuteron collisions in a gas jet had been reported to produce these high energy neutrons.

Dr. Umezawa remarked that there appeared to be many ways of proceeding and in-depth discussions would be needed to sort out the best strategy for choosing among the options.

Closing Remarks

by

G.H. Stevens (NEA)

Mr. Stevens found it encouraging that so many long range and wide ranging ideas on future technology had been presented. He also thought it stimulating that several disparate approaches had been taken; there had been some policy oriented presentations as well as the deeply scientific ones.

One conclusion he could draw was that there was no dissent from the view that research in the fields covered by the Information Exchange Programme was necessarily a long term affair. It did not seem desirable to have a further general meeting within two years but it was highly desirable that, in the meantime, several specialist meetings should be organised to bring together theoreticians and experimentalists, particularly those who could cooperate in using facilities which were scarce. He hoped that participants would volunteer to organise such meetings.

Among worthwhile topics for such meetings he mentioned fundamental physical and chemical data requirements (although he noted that the NEA's Committee on Reactor Physics would bean appropriate body for strengthening cooperation on physics data). Other topics which had been brought up were the chemistry of new partitioning processes and the engineering of accelerators. The NEA could offer an "umbrella" for these meetings if that would be helpful and through collaboration with the IAEA the cooperation of non-OECD countries could be sought. It might be desirable to use funds donated by Japan to have consultants prepare the ground for specialist meetings. If these seemed appropriate conclusions to draw from the meeting he would be happy to discuss their development with the Liaison Officers of the Programme. He invited comment.

Professor Ebert and Dr. Weber supported these proposals in general terms. Dr. Koch counseled that specialist meetings should be small and not attempt to bring together too many different disciplines. He spoke of the possibility of participants joining the meetings organised by his Institute and sought proposals for suitable topics. Dr. Umezawa encouraged all those present to join the task groups organised by the Commission of the European Communities.
In responding to questions Mr. Stevens said that he intended to write to the Liaison Officers shortly with firmer proposals based on the ideas he had put forward, which he was grateful to have heard supported. He had no intention of substituting NEA activity for the coordination performed by Dr. Koch. In regard to the use of the funds donated by Japan, he was minded to mount a review of the data requirements for an overall systems study of the partitioning and transmutation of actinides to see whether it was now possible to improve on earlier analyses of this type.

In concluding, Mr. Stevens expressed his confidence that nuclear energy had an important role to play in future. Ways of using this technology would evolve and it was difficult to know how to choose among the many ways forward. It was necessary to explore many paths in order to become better placed to take decisions. Recalling that the NEA was in some senses an interface body between the scientific and technical communities on the one hand and the governments of Member countries on the other, Mr. Stevens said that the meeting had been extremely useful to him in understanding the questions which were at issue. The NEA was now in a better position to put forward relevant consensus information to the governments. He was therefore extremely grateful to the organisers and the participants and hoped they had derived great benefit also.

Closing of Meeting

by

Dr. H. Umezawa (Japan)

Dr. Umezawa noted the suggestion that the next meeting should be in approximately two years and the desirability of other meetings in the interim period.

He was happy that a provocative set of papers had been presented with many suggestions for further work and believed there had been a good exchange of information. He thanked the Science and Technology Agency, the Japan Atomic Energy Research Institute, PNC and CRIEPI for their sponsorship and support, and Dr. Mukaiyama and Mr. Watanabe for bearing the burden of organizing the meeting.