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COMPARISON OF ACTIVATION CROSS SECTION MEASUREMENTS AND EXPERIMENTAL TECHNIQUES FOR FUSION REACTOR TECHNOLOGY

Summary Report of the IAEA Specialists' Meeting organized by the International Atomic Energy Agency in cooperation with the V.G. Khlopin Radium Institute and held in St. Petersburg, Russia, 7 to 9 September 1994

Prepared by
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February 1995

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ABSTRACT

The report contains the Summary of the IAEA Specialists' Meeting on "Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology". The meeting was organized by the IAEA Nuclear Data Section (NDS) with co-operation and assistance of local organizers from the V.G. Khlopin Radium Institute, KRI, and held in St. Petersburg, Russia, from 7 to 9 September 1994.

The aim of the meeting was to discuss and evaluate the preliminary results of the researches carried out in the framework of the international programme on Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology coordinated by the IAEA Nuclear Data Section and to identify further measurements and actions of participating laboratories. The detailed conclusions and recommendations of the meeting are presented in Attachment 1 of the summary report.

It was confirmed that for further comparison of experimental techniques the experimental groups at JAERI (Tokai, Japan), KRI (St. Petersburg, Russia), IPPE (Obninsk, Russia) and IEP (Debrecen, Hungary) will join in a collaborative program on comparing their measurement techniques and do measurements for reactions where discrepancies between their previous measurements exist. In cases where the JAERI results are the only existing data or deviate strongly from previous measurements, collaboration between KRI, IEP, IPPE and other institutions can consider measurements of these cross sections in order to clarify the situation.

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COMPARISON OF ACTIVATION CROSS SECTION MEASUREMENTS AND EXPERIMENTAL TECHNIQUES FOR FUSION REACTOR TECHNOLOGY

(1) Introduction

In November 1993, the IAEA sponsored a Specialists' Meeting on Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology at the Japan Atomic Energy Research Institute, JAERI, at Tokai in Japan. At this meeting the participants recommended that further work with respect to the 14 MeV cross section measurements is needed to satisfy requirements for fusion reactor technology and recommended also the extension of work to energies below 14 MeV. It was agreed that the follow-up Specialists' Meeting be held in the second half of 1994 at the V.G. Khlopin Radium Institute in St. Petersburg.

(2) Objectives of the Meeting

The aim of the Meeting was to discuss and evaluate the preliminary results of the researches carried out in the framework of the international programme on Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology coordinated by the IAEA Nuclear Data Section and to identify further measurements and actions of participating laboratories.

(3) Organization of the Meeting and Meeting Proceedings

The Meeting was organized by the IAEA NDS with the co-operation and assistance of local organizers of the V.G. Khlopin Radium Institute, KRI, and held in St. Petersburg from 7 to 9 September 1994.

Although the present meeting was attended by only seven people, these particular scientists are very active in the field and very useful discussions were held. The attendants were: H.K. Vonach (Austria), Y. Ikeda and Y. Kikuchi (Japan), A.A. Filatenkov, N.V. Kornilov, A.A. Rimski-Korsakov and K.I. Zolotarev (Russia). The meeting was held in an informal style, leaving ample time for discussions and ad hoc contributions from participants. The participants selected A.A. Rimski-Korsakov, the Deputy Director of KRI, as Chairman of the meeting. The discussions were guided by the following agenda:

- **Measurements of the high priority reactions identified at previous Specialists' Meetings**

  - Preliminary results and plans by the groups
  - Presentations of participants
  - Discussions

- **List of common reactions and measurements for reactions where discrepancies exist**

  - Presentations of participants
  - Discussion on discrepancies

- **Experimental work at energies below 14 MeV**

  - Presentations of participants
  - Discussions

- **Conclusions and Recommendations**

For further details see the meeting Agenda which is given as Attachment 2. The complete list of documents distributed at the Meeting is given below as Attachment 4.

The meeting had a full and excellent support from local organizers.

(4) Results of the Meeting

The above topics were discussed during this meeting and the following comments on what is currently being done in the field of collaboration are drawn from notes and the discussions:

- New measurements have been started or performed at JAERI (Tokai, Japan), KRI (St. Petersburg, Russia), IPPE (Obninsk, Russia) and IEP (Debrecen, Hungary) in cooperation with other institutions.

- A new list of reactions urgently needed for thermonuclear applications has been brought to light by E.T. Cheng, which particularly suggests investigation of reactions important for TOKAMAK reactor diagnostics. For details see Attachment 5.

- New evaluations for monitor reactions have been prepared at IPPE.

- Work on preparation of a recommended 14 MeV cross sections database has been started at KRI.

Regarding the last statement, the meeting participants expressed their concern over the status of 14 MeV activation data. Clearly, more such data exist than of any other type, but, after many decades, there is not a clear trend towards convergence of the values. Actually, during the last decade a wealth of new information has been reported, primarily from several intense machines used for fusion neutronics studies. As D. Smith emphasized earlier (see INDC(NDS)-301/L+F, May 1994), the concern is that the quality of data analysis associated with such measurements (standards, corrections, etc.) has not kept pace with the measurement tools (fluence intensity, radiation detectors, etc.). This is of enormous concern to evaluators. In particular, it generates great difficulties in producing recommended values at 14 MeV to be used in normalizing the results of model calculations for consideration in activation libraries for fusion research. It was agreed to examine the experimental and analytical issues involved in deriving the cross sections from the data.

The next notes are drawn from discussions of the prospects for the future and working plans by groups participating in the collaboration:

- A.A. Rimski-Korsakov informed that possibilities of measurements of most important cross sections listed in "Table of Reaction Priority" (IAEA SPM, November 1993) have been studied and necessary isotopic target materials have been provided at KRI for investigation of the following rections:

$^{92}Mo(n,np)^{91}Nb$	(listed as Priority 1)
$^{92}Mo(n,np)^{91m}Nb$	
$^{64}Ni(n,n'\alpha)^{60}Fe$	(listed as Priority 2)
$^{99}Tc(n,2n)^{98}Tc$	(listed as Priority 2)
$^{204}Pb(n,p)^{204}Ti$	(listed as Priority 2)

  It was pointed out that A.A. Filatenkov will be going to Japan in the fall of 1994 to collaborate with the group at the JAERI-FNS 14 MeV facility. It is recommended that A.A. Filatenkov will do measurements of these reactions in cooperation with JAERI.

- Some reactions on oxygen isotopes have been investigated at JAERI by Y. Ikeda and D. Smith of ANL partly in a collaboration between JAERI and ANL, and preliminary results have been obtained recently. It is recommended that the work on $^{16}O(n,p)^{16}N$, $^{19}F(n,\alpha)^{16}N$, $^{17}O(n,\alpha)^{14}C$, $^{18}O(n,n'\alpha)^{14}C$ and $^{16}O(n,2n)^{15}O$ be continued, since these are of crucial importance for fusion design and plasma diagnostics.

- K.I. Zolotarev presented results of new evaluations for the reactions $^{75}As(n,2n)^{74}As$ and $^{141}Pr(n,2n)^{140}Pr$ which are being used for neutron flux monitoring in the 14 MeV region. He intends to prepare also the evaluation of excitation function for monitor reaction $^{169}Tm(n,2n)^{168}Tm$ taking into account new experimental data.

- It was confirmed that for further comparison of experimental techniques the experimental groups at JAERI, KRI, IEP and IPPE will join in a collaborative program on comparing their measurement techniques and do measurements for reactions where discrepancies between their previous measurements exist. In cases where the JAERI results are the only existing data or deviate strongly from previous measurements, collaboration between KRI, IEP, IPPE and other institutions can consider measurements of these cross sections in order to clarify the situation.

- The meeting recommended to start the effort of compilation of a new evaluated and recommended set of activation cross sections in the neutron energy range around 14 MeV, to be prepared by collaboration members and exchanged first by electronic means among collaborators (KRI, JAERI, IPPE, IEP) and, depending on the progress of this task, discussed by IAEA Nuclear Data Section at one of the following meetings.

- A question was raised about the measurement of ^{28}Si(n,n'p gamma) reaction at 14 MeV which is listed among the priority 1 reactions identified at a previous meeting in Japan. The cross section of this reaction is important for determination of ^{26}Al production in SiC for waste disposal assessment. Reaction product, ^{27}Al, is stable and apparently its cross section can be measured only by non-traditional techniques like acceleration mass spectrometry, which is rather expensive and therefore only rarely used for cross section determination. Someone would need to be supported to take on this task. S. Hlaváč (Bratislava Institute of Physics) suggested that he would be ready to measure this cross section in Bratislava with prompt gamma-ray technique using their present experimental setup (see letter of intent in Attachment 6). It was agreed that IAEA support will be required to fulfill this task.

- H.K. Vonach reported briefly on the results of the informal meeting of the members of the IAEA CRP on "Activation cross sections for the generation of long-lived radionuclides of importance in fusion reactor technology", held at Gatlinburg, USA, on 10 May 1994. The Minutes of the informal meeting (in draft form) are given in Attachment 7. The participants of this SPM considered the results and status of the above CRP and based on the results reported at the Gatlinburg conference in May 1994, they unanimously concluded that this CRP is beeing very successful at relatively low cost to the IAEA as it has involved only research agreements. The original goals of the CRP will be completed by the time of the next CRP meeting; however in the meantime extended data needs for cross sections for generation of long lived nuclides have been presented by the fusion community (see list of reactions presented by E.T. Cheng at the Del Mar CRP meeting and at the Tokai 1993 SPM). It is therefore strongly recommended to use the well-established structure of this CRP to address these new tasks by extending the duration of the CRP for at least one additional 18 months period.

(5) Future Meetings

In conclusion, the participants of the SPM unanimously approved to consider the results of collaboration activity on comparison of activation cross section measurements and experimental techniques at the next meeting which is recommended to be organized as IAEA Consultants' Meeting (CM) and held in Debrecen, Hungary, in 1996.

(6) Acknowledgements

The meeting participants wish to thank the V.G. Khlopin Radium Institute for the warm hospitality and Drs. A.A. Rimski-Korsakov and A.A. Filatenkov for the efficient organization of the IAEA Specialists' meeting.

Attachment 1

Conclusions and Recommendations

(1) Since the previous IAEA Specialists' Meeting on comparison of activation cross section measurements and experimental techniques for fusion reactor technology, held at JAERI, Japan, from 15 to 17 November 1993 and an informal meeting of the IAEA CRP on activation cross sections for the generation of long-lived radionuclides of importance in fusion reactor technology, held in Gatlinburg, USA, on 10 May 1994, the following has been achieved:

(a) New measurements have been started or performed at JAERI (Tokai, Japan), KRI (St. Petersburg, Russia) and IEP (Debrecen, Hungary) in cooperation with other institutions (see Appendix 1*)

(b) A new list of reactions urgently needed for thermonuclear applications has been brought to light by E.T. Cheng, which particularly suggests investigation of reactions important for TOKAMAK reactor diagnostics, that are listed in Attachment 5.

(c) New evaluations for the JENDL activation cross section file provide important data at neutron energies near 14 MeV.

(d) New evaluations for two monitor reactions have been prepared at IPPE.

(e) Work on the preparation of the recommended 14 MeV cross sections database has been started at KRI.

These new developments show successful progress of the collaboration.

(2) Possibilities of measurements of most important cross sections listed in "Table of Reaction Priority" (IAEA SPM, November 1993) have been studied and necessary isotopic target materials have been provided at KRI for investigation of following reactions:

$^{92}Mo(n,np)^{91}Nb$	(listed as Priority 1)
$^{92}Mo(n,np)^{91m}Nb$	
$^{64}Ni(n,n'\alpha)^{60}Fe$	(listed as Priority 2)
$^{99}Tc(n,2n)^{98}Tc$	(listed as Priority 2)
$^{204}Pb(n,p)^{204}Tl$	(listed as Priority 2)

It is recommended that KRI will do measurements of these reactions in cooperation with JAERI.

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* To be compiled by JAERI, KRI, IPPE and IEP.

(3) Some reaction on oxigen isotopes have been investigated at JAERI by Y. Ikeda and D. Smith of ANL partly in a collaboration between JAERI and ANL and preliminary results have been obtained recently. It is recommended that the work on $^{16}O(n,p)^{16}N$, $^{19}F(n,\alpha)^{16}N$, $^{17}O(n,\alpha)^{14}C$, $^{18}O(n,n'\alpha)^{14}C$ and $^{16}O(n,2n)^{15}O$ be continued, since these are of crucial importance for fusion reactor design and plasma diagnostics.

(4) As the reactions $^{75}As(n,2n)^{74}As$ and $^{141}Pr(n,2n)^{140}Pr$ have been used for neutron flux monitoring in the 14 MeV region, it is recommended to take into account data from the evaluation of excitation functions prepared in IPPE. Evaluation of excitation function for monitor reaction $^{169}Tm(n,2n)^{168}Tm$ taking into account new experimental data will be prepared at IPPE.

(5) In relation to the recommendation of previous SPM to develop a new neutron source based on $^{45}Sc(p,n)$ or $^{7}Li(p,n)$ reactions it should be noted that the $^{7}Li(p,n)$ reaction as source of monoenergetic neutrons and neutrons with Maxwell energy distribution at kT=30 keV for capture cross-sections measurement in the keV range was independently investigated and actively used by the KfK group in Germany. It is recommended to inform this group about the data needs for capture cross sections according to the list presented by E.T. Cheng (Action for IAEA/NDS).

(6) The meeting participants are aware of the availability of the new high intensity 14 MeV neutron source SNEG-13 in Russia. It is recommended to use this generator for benchmarking of existing activation data libraries.

(7) For further comparison of experimental techniques the experimental groups at JAERI, KRI and IEP will join in a collaborative program on comparing their measurement techniques and do measurements for reactions where discrepancies between their previous measurements exist. In cases where the JAERI results are the only existing data or deviate strongly from previous measurements, collaboration between KRI, IEP and other institutions can consider measurements of these cross sections in order to clarify the situation.

(8) The meeting discussed the problems connected with the examination of experimental and analytical issues involved in the cross section determination. The meeting supports proposals submitted by D. Smith (see report INDC(NDS)-301/L+F, 1994) and emphasizes the importance of this work. It is strongly recommended to involve on this frame KRI (A.A. Filatenkov) and IPPE (N.V. Kornilov) scientists and present the results of such study to the next meeting for discussion. Both D. Smith of ANL and N.V. Kornilov of IPPE are assumed to be responsible persons for this particular project.

(9) The proposal of S. Hlaváč to study the $^{28}Si(n,n'p\ gamma)$ reaction offers a possibility to determine the important value which cannot be measured by activation because of the stable reaction product. S. Hlaváč is a leading expert in the study of such reactions and posseses a dedicated facility for this purpose. It is therefore strongly recommended that the IAEA/NDS support this study.

(10) The meeting recommends to start the effort of compilation of a new evaluated and recommended set of activation cross sections in the neutron energy range around 14 MeV, to be prepared by collaboration members and exchanged first by electronic means among collaborators (KRI, JAERI, IPPE, IEP) and, depending on the progress of this task, discussed by IAEA Nuclear Data Section at one of the following meetings.

(11) The meeting participants noted that a preparation of the Handbook of recommended 14 MeV cross sections to be issued by the IAEA/NDS would be extremely valuable for many applications. It is recommended that an improved data set of 14 MeV cross section values be created in the framework of a collaborative program taking into account the presently available database.

(12) The meeting appreciates the efforts of D. Smith, ANL, to prepare a review on the status of short-lived activation cross sections. It is recommended to publish this report as an IAEA document for a wide distribution to interested parties.

(13) The meeting supports the recommendation of an informal meeting of the members of the CRP on "Activation cross sections for the generation of long lived radionuclides of importance in fusion reactor technology" in Gatlinburg in May 1994 to arrange the next CRP meeting in Russia in June 1995 (KRI, St. Petersburg or IPPE, Obninsk).

(14) The participants of this SPM considered the results and status of the above CRP and, based on the results reported at the Gatlinburg conference in May 1994, they unanimously concluded that this CRP has been very successful at relatively low cost to the IAEA as it has involved only research agreements. The original goals of this coordinated programme will be completed by the time of the next CRP meeting; however in the meantime extended data needs for cross sections for the generation of long lived nuclides have been presented by the fusion community (see list of reactions presented by E.T. Cheng at the Del Mar CRP meeting and at the Tokai 1993 SPM). It is therefore strongly recommended to use the well-established structure of this CRP to address these new tasks by extending the duration of the CRP for at least one additional 18 months period.

(15) The participants of the SPM unanimously approved to consider the results of the collaboration activity on the comparison of activation cross section measurements and experimental techniques at the next meeting which is recommended to be organized as an IAEA Consultants' Meeting (CM) and to be held in Debrecen, Hungary, in 1996.

Attachment 2

IAEA Specialists' Meeting on

Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology

St. Petersburg, Russia, 7-9 September 1994

Organized in co-operation with the V.G. Khlopin Radium Institute
St. Petersburg, Russia

AGENDA

Wednesday, 7 September

10:00-12:30 **Opening Session**

Opening remarks by Alexander A. Rimski-Korsakov, Deputy Director General of the V.G. Khlopin Radium Institute and Anatoly B. Pashchenko, IAEA Nuclear Data Section

- Election of Chairman
- Adoption of Agenda and Time Schedule
- Announcement of Organizational Matters

Session 2: Measurements of the high priority reactions identified at previous Specialists' Meeting

- Preliminary results and plans by the groups
- Presentations of participants
- Discussions

12:30-14:00 *Lunch break*

14:00-17:30 **Session 3: List of common reactions and measurements for reactions where discrepancies exist**

- Presentations of participants
- Discussion on discrepancies

<u>**Thursday, 8 September**</u>

9:30-12:30 **Session 4: Experimental work at energies below 14 MeV**

- Presentations of participants
- Discussions
- Formation of Working Group to draft the conclusions and recommendations of the meeting

12:30-14:00 *Lunch break*

14:00-17:30 **Session 5: Conclusions and Recommendations**

- Drafting of meeting conclusions and recommendations

<u>**Friday, 9 September**</u>

9:00-12:00 **Session 5** (continued)

- Completion of Working Group Report

12:00-13:00 *Lunch Break*

13:00-17:00 **Session 6: Final Considerations**

- Discussion of Conclusions and Recommendations
- Corrections and Adoption of Final Report
- Adoption of the Schedule of Work and Future Meetings
- Closing of the Meeting

List of Proposed Presentations

(1) ***A. Filatenkov***, "Experimental and analitical issues involved in deriving the cross sections from the data".

(2) ***A. Filatenkov***, "Accuracies to which various reactions can be measured on the basis of current technology".

(3) ***A. Filatenkov***, "Contribution of collaboration members to the preparation of the IAEA Handbook of Evaluated 14 MeV Cross Sections for Applications".

(4) ***N. Kornilov et.al.*** "Activation cross sections for ^{151}Eu(n,2n), ^{153}Eu(n,2n), ^{58}Ni(n,2n), ^{58}Ni(n,np) reactions at 14.8 MeV neutron energy".

(5) ***N. Kornilov et.al.*** "Investigation of the ^{10}B(n,t) reaction in sub-barrier region".

Attachment 3

Specialists Meeting

"Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology"

St. Petersburg, Russia

7 - 9 September 1994

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Attachment 4

IAEA Specialists' Meeting on

Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology

St. Petersburg, Russia, 7-9 September 1994

LIST OF DOCUMENTS DISTRIBUTED AT THE MEETING

SPM/St.Ptsb94/P-1	Tentative Agenda and List of Presentations
SPM/St.Ptsb94/P-2	List of Participants
SPM/St.Ptsb94/P-3	Report INDC(NDS)-301, 1994. Summary Report of Specialists' Meeting on "Comparison of Activation Cross Section Measurements and Experimental Techniques for Fusion Reactor Technology", JAERI, Japan, 15-17 November 1993.
SPM/St.Ptsb94/P-4	INDC(NDS)-286, 1993. Proceedings of the Second Research Co-ordination Meeting on "Activation Cross Sections for the Generation of Long-Lived Radionuclides of Importance in Fusion Reactor Technology", Del Mar, USA, 29-30 April 1993.
SPM/St.Ptsb94/P-5	INDC(NDS)-288, 1993. Summary Report of the Second Research Co-ordination Meeting on "Activation Cross Sections for the Generation of Long-Lived Radionuclides of Importance in Fusion Reactor Technology", Del Mar, USA, 29-30 April 1993.
SPM/St.Ptsb94/P-6	Summary (draft) of the informal meeting of the members of the CRP on "Activation Cross Sections for the Generation of Long-Lived Radionuclides of Importance in Fusion Reactor Technology", held at Gatlingburg, USA, 10 May 1994.
SPM/ST.Ptsb94/P-7	Letter from Dr. Lu Hanlin. Preliminary results of new measurements of the near threshold reactions.

Attachment 5

URGENT NUCLEAR DATA NEEDS FOR TOKAMAK REACTOR DIAGNOSTICS

E.T. Cheng, TSI Research

(1) Summary

A recent workshop at PPPL (March 1994) on DT experiments revealed needs of nuclear data at energies above 14 MeV for the determination of alpha particle slowing down in the DT plasma. A theory has been derived by Ray Fisher et al. of General Atomic to estimate the production of higher than 14 MeV neutrons due to the transfer of alpha energy to tritons during the slowing down of DT alpha particles. Up to 3.4 MeV tritons are to be produced in the DT plasma and capable of generating neutrons of energies up to 20.6 MeV. The higher than 14 MeV neutron flux will be about 4 to 6 orders of magnitude lower than the background 14 MeV neutrons. Activation detectors have been proposed by Fisher et al. to measure the higher than 16 MeV neutron flux. This technique can be readily applicable to the near-term TFTR and JET DT operations, as well as future ITER operations. This memo describes the threshold neutron reactions selected for the above-mentioned diagnostic technique. The urgent nuclear data needs can thus also be identified.

(2) Selection of Threshold Neutron Reactions

Several reactions were proposed by R. Fisher et at. (Refs. 1 and 2). Additional reactions were suggested after discussions with R. Fisher and F. Mann (Westinghouse-Hanford). All of these reactions are described below:

(a) **$^{16}O(n,2n)^{15}O$**. The reaction threshold is 16.7 MeV. It emits a positron during the decay with an average energy of 0.735 MeV. The half-life is 2.04 min. It has a good threshold energy to distinguish from the high energy neutron tail (about 15 - 16 MeV) due to beam-beam and beam-plasma reactions. The only interference is from the 16.7 MeV D-T gamma radiation which may trigger the $^{16}O(\gamma,n)^{15}O$ reaction.

(b) **$^{9}Be(n,d)^{8}Li$ and $^{9}Be(n,np)^{8}Li$**. The threshold energies for $^{9}Be(n,d)$ and $^{9}Be(n,np)$ reactions are 16.3 and 18.8 MeV, respectively. The main reaction is $^{9}Be(n,d)^{8}Li$ because the flux level at 19 MeV and above is going to be very small compared to the 17 MeV neutron flux. The reaction product, ^{8}Li, has a half-life of 838 ms, and emits a beta particle with an average energy of 6.24 MeV. This reaction has

2 problems. One is that the short-lived activation product requires rapid transfer to a radiation quiet area for decay gamma measurements. The other problem is that there are competing activation decays (background). A Cherenkov-type detector is probably required to see the signal by observing the >10.4 MeV betas.

(c) **$^{12}C(n,2n)^{11}C$**. The threshold energy is 20.3 MeV. Carbon-11 has a half-life of 20.4 min and emits a positron with an average energy of 0.385 keV. This is a less desirable reaction due to its high threshold energy which results in a very small signal.

(d) **$^{20}Ne(n,2n)^{19}Ne$**. The threshold is 17.7 MeV. The half-life of ^{19}Ne is 17.2 s and ^{19}Ne emits a positron of 0.963 MeV average energy. The threshold of this reaction may be too high. The high energy (γ,n) reaction with the ^{20}Ne isotope is a concern. There also may exist a lower than 14 MeV threshold, interfering reaction with one of the Ne isotope, $^{22}Ne(n,\alpha)^{19}O$. The activation product, ^{19}O, has a half-life of 26.9 s and emits a beta particle at 1.74 MeV average energy and a gamma ray at 939 keV. The $^{20}Ne(n,p)^{20}F$ reaction has a half-life of 11 s and emits high energy gamma as well as betas. Because of this high background activity, the $^{20}Ne(n,2n)$ reaction may not be feasible as a diagnostics reaction.

(e) **$^{20}Ne(n,t)^{18}Fe$**. The threshold energy is 15.5 MeV. The activation product, ^{18}F, has a relatively long half-life, 110 min, and produce positrons during the disintegration. The average energy of the positrons is 242 keV. The relatively low threshold energy is a concern due to beam-beam and beam-plasma neutrons on TFTR and JET, and ICRF tail generated neutrons on ITER.

(f) **$^{24}Mg(n,t)^{22}Na$**. The threshold energy is 16.3 MeV, ideal for the diagnostic technique. The activation product, ^{22}Na, is a relatively long-lived isotope, 2.6 y half-life. It emits a relatively high energy gamma, 1.27 MeV. The only concern is that the activity may be too insignificant to be detected. The accelerator mass spectrometry (AMS) method may be needed for the measurement.

(g) **$^{30}Si(n,^{3}He)^{28}Mg$**. The threshold energy is 16.8 MeV, ideal for all experimental reactors. The activation product, ^{28}Mg, has a half-life of 20.9 h and emits a gamma with 1.37 MeV average energy. This is a very attractive reaction, although there may exist a concern that the signal may be too small to be significant for both TFTR and JET due to the relatively long half-life. However, a competing reaction, $^{29}Si(n,2p)^{28}Mg$, may rule out the use of this reaction if the threshold proves to be lower than 14 MeV.

(h) **$^{28}Si(n,t)^{26}Al$**. The reaction threshold is 16.7 MeV, ideal for all experimental reactors. Aluminium-26 has a half-life of 7.2e+05 y, and emits high energy gammas during disintegration. The signal is so small that the AMS method may be needed to complete the measurement.

(i) **^{93}Nb(n,3n)^{91m}Nb**. The threshold energy is 16.8 MeV. ^{93}Nb is a well known dosimeter indicating that high purity niobium is available. The activation product, ^{91m}Nb, has a half-life of 62 d and emits 1.2 MeV gamma (4%). There are 2 reactions of concern with the background 14 MeV neutrons. One is ^{93}Nb(n,2n)^{92m}Nb, a popular dosimeter reaction for 14 MeV neutrons. The half-life of ^{92m}Nb is 10.2 d and emits a 935 keV gamma. The other is ^{93}Nb(n,α)^{90}Y which has a much shorter half-life of 64 h and emits MeV energy betas. These 2 reactions, however, are very likely to be discriminated from the 1.2 MeV gamma signal and longer half-life of ^{91m}Nb.

(j) **^{113}In(n,3n)^{111}In**. The threshold energy is 17.1 MeV and ^{111}In emits gammas with 171 and 245 keV energies. However, there is an interfering reaction at 14 MeV, ^{113}In(n,α)^{110}Ag. ^{110}Ag has a half-life of 250 d and emits 1.51 and 1.38 MeV gammas that may swamp the signal from ^{111}In.

(k) **^{115}In(n,3n)^{113m}In**. The threshold energy is 16.3 MeV. ^{113m}In emits a gamma of 392 keV with a half-life of 1.66 h. However, there are several interfering reactions, ^{115}In(n,p)^{115}Cd (h.l. 53.5 h; 528 & 336 keV gammas), ^{115}In(n,2n)^{114m}In (h.l. 50 d; 725 & 560 keV gammas), and ^{115}In(n,α)^{112}Ag (h.l. 3.13 h; 1.39 MeV & 617 keV gammas).

(3) Charged Particle Cross Sections

All DT related charged-particle reactions are needed. These include both DT and DD fusion and scattering cross sections, as well as D^{4}He and T^{4}He scattering cross sections. The slowing down of alpha particles in the plasma and energy transfer to tritons can not be correctly calculated without the reliable knowledge of these reaction and scattering cross sections. The existing information on T^{4}He cross sections is especially limited.

(4) Urgent Nuclear Data Needs

Based on Sec. 2 and Sec. 3, the urgent nuclear data needs are identified as follows:

(a) **^{16}O(n,2n)^{15}O**. From threshold to 20.6 MeV. High priority.

(b) **^{16}O(γ,n)^{15}O**. From threshold to 20.6 MeV. High priority.

(c) **^{9}Be(n,d)^{8}Li**. From threshold to 20.6 MeV.

(d) **^{12}C(n,2n)^{11}C**. Above 20.3 MeV. Low priority.

(e) **^{12}C(γ,n)^{11}C**. Above threshold. Low priority.

(f) **$^{20}Ne(n,2n)^{19}Ne$.** From threshold to 20.6 MeV. Low priority.

(g) **$^{20}Ne(\gamma,n)^{19}Ne$.** Above 17 MeV. Low priority.

(h) **$^{22}Ne(n,\alpha)^{19}O$.** From threshold to 16 MeV. Low priority.

(i) **$^{20}Ne(n,t)^{18}F$.** From threshold to 20.6 MeV. High priority.

(j) **$^{24}Mg(n,t)^{22}Na$.** From threshold to 20 MeV. High priority.

(k) **$^{30}Si(n,He3)^{28}Mg$.** From threshold to 20.6 MeV. Low priority.

(l) **$^{29}Si(n,2p)^{28}Mg$.** From threshold to 20.6 MeV. Low priority.

(m) **$^{28}Si(n,t)^{26}Al$.** From threshold to 20.6 MeV. High priority.

(n) **$^{93}Nb(n,3n)^{91m}Nb$.** From threshold to 20.6 MeV. High priority.

(o) THe4 scattering differential and angular cross sections. Helium-4 energy is from 0.3 to 3.5 MeV. High priority is given at 3.5 MeV. More precise energy transfer data is needed.

(5) Impact on Low-activation Materials

The enhanced population of higher than 14 MeV neutrons due to the slowing down of alpha particles in the plasma may impose a new limit on the development of low-activation materials for fusion. An investigation in this area is being planned. An example is the $^{28}Si(n,t)^{26}Al$ reaction that may increase the long-lived ^{26}Al activity and change the waste disposal rating of SiC as the first wall material.

<u>REFERENCES</u>:

[1] R. Fisher et al., "Alpha Particle Diagnostics Using Knock-on Ion Tails", Proc. Workshop on DT Experiments, March 2-4, 1994, PPPL.

[2] R. Fisher et al., "A New Alpha Particle Diagnostics Using Knock-on Ion Tails", presented at the 10th Topical Conference on High Temperature Plasma Diagnostics, Rochester, NY, May 1994, and available as a GA report, GA-A21715; to be published in Review of Scientific Instruments, October 1994.

Attachment 6

Letter of intent

Measurement of ^{28}Si(n,n'pγ) cross section at 14 MeV

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Engineering design of fusion reactor requires large amount of nuclear data, mainly cross sections of various neutron induced reactions. Different activities leading to improvement of our present understanding of nuclear cross sections are coordinated partly by the Nuclear Data Section of the IAEA. In the recent Summary Report [1] of the IAEA Specialist's Meeting on Comparison of Activation Cross Section Measurement and Experimental Techniques for Fusion Reactor Technology held in JAERI 1993, cross sections of primary importance for fusion reactor technology are given. These are mainly cross sections, which may be obtained by activation technique.

Among the Priority 1 Reactions given in Table 1 of ref. [1], the reaction ^{28}Si(n,n'p)^{27}Al is also listed. Cross section of this reaction is important for determination of ^{26}Al production in SiC for waste disposal assessment via subsequent ^{27}Al(n,2n) rection. The intermediate reaction product – ^{27}Al is stable and apparently its cross section can be measured only by nontraditional techniques like accelerator mass spectrometry, which is rather expensive and therefore only rarely used for cross section determination.

However, recently developed prompt γ ray technique may provide at least part of the required cross section, as was successfully demonstrated in the case of the ^{16}O(n,$\alpha\gamma$) reaction [2]. This technique is based on prompt γ ray cross section measurement and provide the cross section of excited states population in the product nucleus. This experimental information may be further combined with theoretical estimation of relative branching to ground and excited states, respectively. These two pieces of information may provide rather reliable cross section of reaction of interest, which may otherwise be difficult to get.

The abovementioned method is based on the assumption, that at least one excited state is populated during the reaction. Population of excited states depends very much on the available energy. Q-value of the ^{28}Si(n,n'p)^{27}Al reaction is -11.58 MeV, therefore at 14 MeV incident neutron energy only first and probably second excited level in ^{27}Al at energies 843.8 and 1014.5 keV may be observed. That this is really the case is demonstrated in fig.1, which shows two prompt γ ray spectra in the region of 840 keV. Spectrum from Si + n reaction at 14.7 MeV incident neutron energy using only 38 g Si sample is shown in the upper part. This measurement was not optimized for the present purposes and the statistics is rather poor. Nevertheless, it shows clearly distinguished peak at 843.8 keV, which we identify as the γ ray transition from the ^{28}Si(n,n'pγ)^{27}Al reaction. In the lower part of fig. 1 a spectrum from CrO_3 + n at the same neutron energy is shown for comparison. At the energy of 846.0 keV a strong peak from ^{52}Cr(n,pγ)^{52}V is visible. However, in both spectra a weak background peak at 833.8 keV from ^{72}Ge(n,n'γ) reaction is visible. Position of this background peak in both spectra shows, that our energy calibration is correct. From comparison of both spectra following conclusions may be drawn

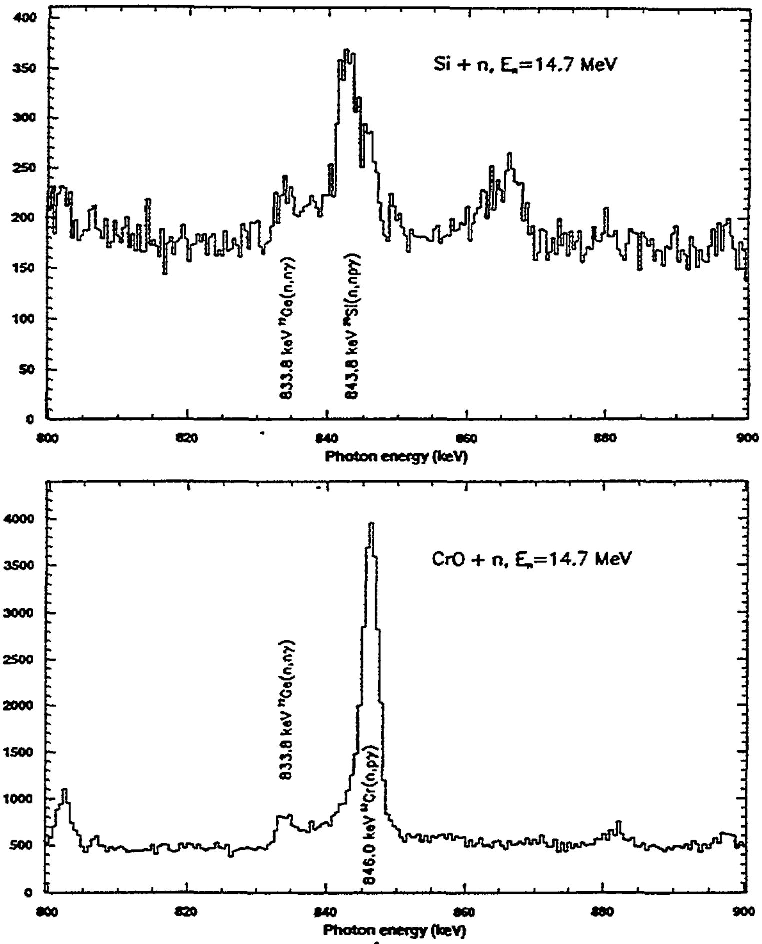

Figure 1: *Part of the prompt γ ray spectra from the Si + n and CrO_3 + n reactions at 14.7 MeV incident neutron energy. Un the upper spectrum a peak at 843.8 keV from ^{28}Si(n,n'pγ)^{27}Al is visible. Asymmetry of this peak is caused by a weak background contribution at 846.8 keV. Spectrum from CrO_3 + n in the lower part does not show peak at 843.8 keV. Typical background peak at 833.8 keV from neutron scattering in HPGe detector itself, visible in both spectra may serve for comparison of energy scale and intensity in both spectra.*

- The 843.8 keV transition is clearly produced in neutron reaction with Si and the only possible reaction is ^{28}Si(n,n'p)^{27}Al. The 843.8 kev peak is slightly contaminated from 846.8 keV background transition from neutron interaction with Fe components of HPGe detector itself.

- The expected uncertainty of cross section after optimalization of the experiment for (n,n'pγ) cross section measurement is better than 10 %, partly because relative measurement with respect to ^{28}Si(n,n'γ) may be performed.

- The Si + n spectrum shows, that probably also measurement of population of the 1014.5 keV level in ^{27}Al is feasible.

Therefore measurement of the ^{28}Si(n,n'pγ) cross section with prompt γ ray technique using our present experimental setup seems to be feasible and may provide cross sections with acceptable uncertainties. This experimental information may be combined with recent theoretical results thus providing cross section value of the ^{28}Si(n,n'p) reaction, which is listed as priority 1 reaction in the ref. [1]. We intend to measure this cross section in Bratislava as a part of the international experimental collaborative effort Bratislava-Vienna using our well equipped neutron generator [3] and efficient spectroscopy techniques [4]. We seek support for this intention in the international community of activation nuclear data.

References

[1] A. B. Pashchenko, Comparison of Activation cross section measurements and experimental techniques for fusion reactor technology, IAEA Report INDC(NDS)-301, (IAEA Vienna, July 1994).

[2] S. Hlaváč, P. Obložinský, I. Turzo, L. Dostál and J. Kliman, Cross section of the ^{16}O(n,$\alpha\gamma$) reaction at 14.7 MeV, IAEA Report INDC(SLK)-002, (IAEA Vienna, August 1994).

[3] J. Pivarč and S. Hlaváč, The multipurpose 14-MeV Neutron Generator at Bratislava, Nucl. Sci. Eng. 106 (1990) 266.

[4] S. Hlaváč, P. Obložinský, I. Turzo, L. Dostál, H. Vonach, A. Pavlik and S. P. Simakov, Study of γ Radiation from Interaction of 14.7 MeV Neutrons with ^{208}Pb, Nucl. Sci. Eng, accepted for publication.

Attachemnt 7

Minutes of the informal meeting of the members of the CRP on activation cross sections for the generation of long-lived radionuclides of importance in fusion reactor technology, held at Gatlinburg, USA, on May 10th 1994

1) **Participants of the meeting:**

E. Cheng (Chairman)
H. Vonach (Secretary)
Y. Ikeda
D.L. Smith
W. Mannhart
A. Pavlik
V. Avrigeanu
F. Mann
N. Molla
S. Qaim
Y. Xia (Sichuan University Chengdu)
X. Long (Sichuan University Chengdu)
J. Kopecky
M. Chadwick
J. Reffo
P. Oblozinsky

2) **Progress Reports and plans for future work**

All CRP-participants reported on their work since the last CRP-meeting at Del Mar, April 1993, and their plans until the next CRP-meeting in summer 1995. In addition valuable contributions were also given by some of the participants not formally members of the CRP.

In detail the following reports were given:

a) *D.L. Smith:*

14 MeV cross sections given before may undergo slight revisions. Measured cross sections in Be-d neutron field will be compared with theory.

b) *W. Mannhart:*

Will measure $^{159}Tb(n,2n)^{158}Tb$ and $^{151}Eu(n,2n)^{150m}Eu$ cross sections at $E_n \approx 9 - 11$ MeV.

c) *Y. Ikeda:*

Plans measurement of the $^{28}Si(n,np)^{27}Al$ cross section by AMS, will perform further measurements of the $^{187}Re(n,2n)^{186m}Re$ and $^{193}Ir(n,2n)^{192m2}Ir$ cross sections at $E_n \approx 14$ MeV after longer cooling time of the samples irradiated some time ago.

d) *S. Qaim:*

$^{63}Cu(n,p)^{63}Ni$ cross section measurements are still in progress, will be completed before the next CRP-meeting, new measurements of $^{151}Eu(n,2n)^{150m}Eu$, $^{159}Tb(n,2n)^{158}Tb$, and $^{109}Ag(n,2n)^{108m}Ag$ (sep. Isot.) at E_n = 10 - 11 MeV have been started, He irradiations have already been performed.

e) *Y. Xia and X. Long, Sichuan University, Chengdu:*

A number of activation cross section measurements for (n,γ) reactions have been performed in the neutron energy range .022 - 1 MeV. A short written progress report is given as appendix to this report.

f) *H. Vonach:*

Has included all cross section values reported at Del Mar into his evaluation of 14 MeV cross sections, will continue by updating their evaluation for the planned final report on the CRP.

3) Cross section for the $^{28}Si(n,np)^{27}Al$ reaction. E. Cheng stressed the importance of this reaction because of the production of long-lived ^{26}Al in a two step reaction. It was pointed out that two new evaluations on Si from Oak Ridge and Dr. Reffo, Bologna, give theoretical predictions of this cross section. In addition it was suggested to communicate the problem to Dr. B. Strohmaier who has recently also done model calculations in this mass range.

4) Next CRP-meeting

The participants unanimously agreed to the present IAEA proposal to hold the meeting in the Russian Republic and expressed the wish to have the meeting at St. Petersburg in June 1995 if this is possible.

5) Final report of the CRP

There was general agreement that the final report summarizing the results of this very successful CRP should be produced at the next CRP-meeting. It was suggested that final reports from all participants should be sent to the IAEA-NDS up to end of March 1995 and the joint final report should be drafted jointly by Dr. Pashchenko and Dr. Vonach for discussion at the CRP meeting.

6) Follow-up CRP

There was general agreement that a follow-up CRP on experimental study of important activation cross sections would be very useful.