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S. Pelloni (EIR), E. T. Cheng (GA), M. J. Embrechts (RPI)

Eidgenössisches Institut für Reaktorforschung
Institut Fédéral de Recherches en Matière de Réacteurs
Swiss Federal Institute for Reactor Research

CH-5303 Würenlingen Tel. 056 99 21 11 Telex 82 7417 eir ch

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SELF-SHIELDING CHARACTERISTICS OF AQUEOUS SELF-COOLED BLANKETS FOR NEXT GENERATION FUSION DEVICES

Sandro Pelloni[1] **Edward T. Cheng[2]** **Mark J. Embrechts[3]**

[1]Swiss Federal Institute for Reactor Research, Würenlingen, Switzerland
Work performed while on leave at Rensselaer Polytechnic Institute
[2]General Atomic Technologies Inc., San Diego, CA, USA
[3]Rensselaer Polytechnic Institute, Troy, NY, USA

Zusammenfassung

In dieser Studie wird die Resonanzabschirmung anhand von zwei zukunftsorientierten einfachen Fusionskonzepten untersucht. Die untersuchten wassergekühlten Blankets, die nur aus Strukturmaterial und aus im Wasser gelösten Brutmaterial Li-Hydroxyd bestehen, sind durch eine einfache Technologie gekennzeichnet. Sie bilden die innern Blankets einer Fusionsmaschine, und eignen sich besonders für Materialtests. Sie dienen primär zur Abschirmung, aber auch zur Tritiumproduktion. Die beiden Konzepte beziehen sich auf die gegenwärtig studierten europäischen und amerikanischen Torus-Experimente (NET und TIBER II/ETR). Rostfreier Stahl bzw. Wolfram werden als Strukturmaterialien verwendet. Das Ziel dieser Studie liegt darin, Heterogenitäts- und Abschirmungseffekte in solchen wassergekühlten Systemen zu analysieren. Es wird gezeigt, dass in einem aus rostfreiem Stahl bestehenden Blanket (NET-Typ) keine Zunahme der Tritiumbrutrate erzielt werden kann, wenn die Resonanzabschirmung berücksichtigt wird. Im Gegensatz dazu wird die Tritiumbrutrate des Wolfram-strukturierten Blankets (TIBER-Typ) durch Abschirmung der Resonanzquerschnitte um 5% erhöht. Diese Zunahme kann durch Heterogenitätsbetrachtungen noch mehr erhöht werden.

Abstract

The present study examines self-shielding characteristics for two aqueous self-cooled tritium producing driver blankets for next generation fusion devices. The aqueous Self-Cooled Blanket concept (ASCB) is a very simple blanket concept that relies on just structural material and coolant. Lithium compounds are dissolved in water to provide for tritium production. An ASCB driver blanket would provide a low technology and low temperature environment for blanket test modules in a next generation fusion reactor. The primary functions of such a blanket would be shielding, energy removal and tritium production. One driver blanket considered in this study concept relates to the one proposed for the Next European Torus (NET), while the second concept is indicative for the inboard shield design for the Engineering Test Reactor proposed by the USA (TIBER II/ETR).The driver blanket for NET is based on stainless steel for the structural material and aqueous solution, while the inboard shielding blanket for TIBER II/ETR is based cn a tungsten/aqueous solution combination. The purpose of this study is to investigate self-shielding and heterogeneity effects in aqueous self-cooled blankets. It is found that no significant gains in tritium breeding can be achieved in the stainless steel blanket if spatial and energy self-shielding effects are considered, and the heterogeneity effects are also insignificant. The tungsten blanket shows a 5 percent increase in tritium production in the shielding blanket when energy and spatial self-shielding effects are accounted for. However, the tungsten blanket shows a drastic increase in the tritium breeding ratio due to heterogeneity effects.

1 INTRODUCTION

One of the primary goals of next generation fusion devices worldwide is the testing of the reactor components. In the United States of America this class of devices is designated as Engineering Test Reactors (ETR) and the current ETR design is labeled "TIBER II"[1].

Because of the compactness of the TIBER II design the minimalization of the inboard shield is one of the major constraints. The primary function of this inboard shield is the protection of the superconducting coils from radiation effects. In addition it is desirable to breed as much tritium as possible in this minimal thickness inboard shield without compromising the shielding requirements. The Next European Torus (NET)[2] is the fusion device which would follow JET (Joint European Torus).[3] Its main objective is to demonstrate fusion energy in a plant which integrates the essential technologies of a fusion reactor. In the first phase, the plasma physics testing phase, NET would operate with a low temperature minimal thickness shielding blanket to maximize the room in the plasma chamber. In the technology phase of the NET project, the shielding blanket could be converted to a tritium producing driver blanket by dissolving lithium compounds in the coolant.

One of key design issues of next term fusion devices relates to the incorporation of a reliable low technology driver blanket. Such a blanket would be operated at low temperature (40 - 70 degrees Celsius) and would allow sufficient room for the insertion of test modules where more advanced reactor blanket concepts will be tested. The primary goals of this driver blanket are shielding and tritium production. Depending on the design philosophy net tritium breeding may or may not be a requirement, but as long as the design complexity and shielding performance are not affected, a maximal tritium production performance would either reduce the cost of external tritium to be purchased, or increase the available space for blanket and materials testing. While tritium self-sufficiency is not required for NET, it will be required for TIBER II.

Recently a novel blanket concept for next generation fusion devices has been proposed. This concept relies on just structural material and water, whereby small amounts of lithium compound are dissolved in the water to provide for tritium production. This concept is designated as the aqueous self-cooled blanket (ASCB) concept.[4] An isotopic tritium extraction technique would be required to provide for tritium. Stainless steel is proposed for the structural material for the NET ASCB driver blanket design.[5] TIBER II relies on beryllium and stainless steel for the ASCB driver blanket. The beryllium would act as a neutron multiplier, while a small fraction of stainless steel would provide for structural support. Because of the limited space available on the inboard side for the TIBER II design, a minimal thickness ASCB shielding blanket based on tungsten has been proposed.[6] The low technology aspects of the aqueous self-cooled blanket concept make this design option well suited for near term devices.

In this study neutronics aspects for two tritium producing shielding blankets are addressed. These blankets are indicative for the shielding blankets proposed in NET and TIBER II, but are simplified further to allow a more clear understanding of the neutronics phenomena involved. The first configuration applies to the NET design and consists of 75 percent (by volume) low-carbon stainless steel, SS316L, and 25 percent (by volume) aqueous solution with 10 g $^{6}LiOH$ dissolved per 100 cc of water. The second concept is indicative for the inboard shielding blanket for the TIBER II design and is composed of 75 percent (by volume) tungsten, 15 percent aqueous solution (with 10 g ^{6}LiOH per 100 cc H_2O) and 10 percent primary candidate stainless steel (PCASS) for structural integrity. The ^{6}Li content is a very important parameter in this system. Lithium was assumed to be fully enriched with ^{6}Li for the computational purpose only. The actual LiOH quantity is determined by the actual ^{6}Li enrichment in the aqueous coolant.

The main issue in the investigations presented here relates to the self-shielding characteristics of the aqueous self-cooled blanket concept. Previous studies[7] have already shown that the self-shielding treatment of resonance cross sections could enhance the calculated values for tritium breeding ratio. The next two sections report on a detailed description for the geometry and nuclear data used. Section 4 summarizes the results from the various calculational models, while section 5 presents a sensitivity analysis for the tungsten blanket. The final conclusions and recommendations for further investigations are given in section 6.

2 NUCLEAR DATA

All nuclear data are based on the ENDF/B-V[8] and EFF-1[9] evaluations. For discrete-ordinates calculations two basic libraries were considered: MATXS6 and an EIR file based on EFF-1.

MATX6 is an 80 neutron group ENDF/B-V Los Alamos library, which is primarily intended for fast reactor analysis and for fusion related applications.[10] These data feature extensive self-shielded cross sections for temperatures from 300 K up to 5000 K. Background cross sections vary from infinity down to a lower limit that depends on the material.

The second data library is a MATXS like file, but is based on the newest European evaluation EFF-1, and was generated at EIR using the NJOY[11] system. This file is based on the VITAMIN-J[12] 175 neutron group boundaries (corresponding to the VITAMIN-E[13] structure plus one group missing from VITAMIN-C[14]). Cross sections up to P_6 are included for a broad class of materials pertaining to fusion, fission, and activation purposes. Temperatures range from 300 K to 3000 K. Data are tabulated for 10^{10}, 10^4, 10^3, 100, 10 and 0.1 barns dilution cross sections. The method of the pointwise slowing down flux calculator for a single absorber in an infinite moderator was used in the NJOY-GROUPR runs to shield resolved resonances. The standard VITAMIN-E weighting spectrum was selected for collapsing all point data into multi-group VITAMIN-J cross sections.

In order to process self-shielded and infinitely dilute cross-section libraries for the discrete-ordinates calculations, the MATXS files were treated with the TRANSX-CTR code.[10] The correct blanket geometry, including all atomic densities and mean chord lengths for heterogeneous regions (spatial self shielding) were considered in TRANSX-CTR. Transport cross sections were as usual determined using the Bell-Hansen- Sandmeier[10] transport correction. After processing the MATXS libraries with TRANSX-CTR, a card image cross section library was generated. This card image library was then used in the ONEDANT[15] one-dimensional neutral particle discrete ordinates transport code for direct and adjoint spectrum calculations.

The Moute Carlo calculations in this study are based on MCNP.[16] The standard continuous and 282-group discrete RMCCS and DRMCSS ENDF/B-V data libraries[16] were employed.

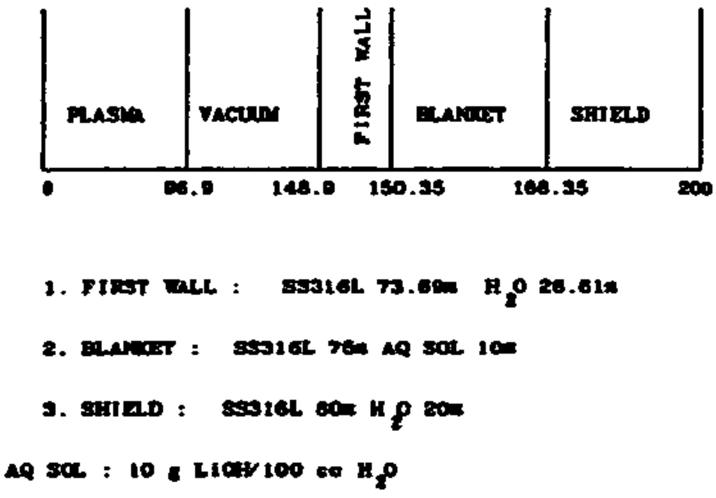


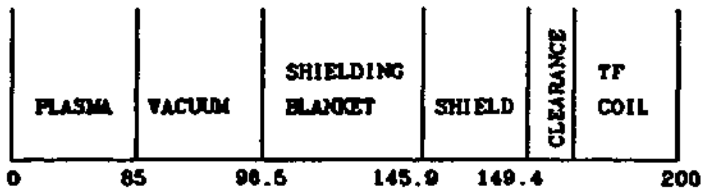
Figure 1: Geometry description for the NET related blanket

3 COMPUTATIONAL MODEL

In the present reference study two aqueous self-cooled blanket (ASCB) options were selected for in order to investigate the effects of self shielding. One option relates to the NET design[5], while the second choice will be indicative for a tungsten based inboard shielding blanket design for TIBER.[6] Both ASCB blankets employ 10 grams of dissolved lithium-hydroxide per 100 grams of water as the coolant and tritium breeding medium.

The first blanket option (related to NET) utilizes stainless steel, whereas the second option employs tungsten for the structural material. An infinite homogeneous model of the first system consists of a 96.9 cm thick plasma region, followed by a 52 cm thick scrape-off zone, a 1.45 cm thick first wall consisting of 73.69 (vol.) percent stainless steel and 26.31 percent water, a 16.0 cm thick blanket made up of 75 percent stainless steel, 25 percent water mixed with lithium compound (e.g. 10 g ^{6}LiOH dissolved in 100 cm^3 water), and a 33.65 cm thick shield of 80 percent stainless steel and 20 percent water (Fig. 1).

The second concept uses an 85 cm thick plasma, followed by a 11.5 cm thick vacuum region, a 49.4 cm thick shielding blanket consisting of 75 percent tungsten (at 90 percent of its maximal theoretical density), 10 percent PCASS, 15 percent water mixed with lithium compound (i. e. 10 g ^{6}LiOH dissolved in 100 cm^3 of water), a 3.5 cm thick shield consisting of 85 percent boron carbide (at 86 percent of its maximal theoretical density), 10 percent PCASS, 5 percent water mixed with lithium-hydroxide, a 2 cm thick vacuum clearance zone, and a 48.6 cm thick uniform copper region simulating the toroidal field (TF) coils (Fig.2). A vacuum boundary condition on the outer reflector region simulates leakage effects.



1. SHIELDING BLANKET : W 75% (at 90% t.d.)
PCASS 10% AQ SOL 15%

2. SHIELD : B_4C 85% (at 86% t.d.) PCASS 10%
AQ SOL 5%

3. TF-COIL : Cu 100%

AQ SOL : 10 g LiOH/100 cc H_2O

Figure 2: Geometry description for the TIBER related blanket

The densities utilized for the homogeneous blanket descriptions corresponding to Figures 1 and 2 are summarized in Tables I and II. In both cases the ASCB blanket consists of just structural material and water as coolant with small amounts of lithium compound (^{6}LiOH) dissolved in the water in order to breed tritium (Tables I and II). The tungsten based inboard ASCB blanket for TIBER-II will have good shielding characteristics in view of the the high epithermal neutron and gamma absorption cross sections of tungsten (see Figs 3-4).

Since tungsten is a neutron multiplier at high energies (see Fig. 4), and both absorption and (n,2n) cross sections compete (see Figs. 3-4) some heterogeneous models of the shielding blankets were also considered. In the heterogeneous models the blanket was subdivided into equivalent regions of the same volume containing alternating regions of aqueous solution and structural material.

All discrete-ordinates calculations were performed using the one-dimensional transport code ONEDANT with a P_3S_{16} approximation. Each mesh had the width of one centimeter. Doubling the number of meshes did not affect the results presented in this paper. The fusion neutron source lies in the third group of the MATXS6 energy structure and was assumed to belong 40 percent in the 7th group and 60 percent in the 8th group of the VITAMIN-J structure (a different split did not influence these results).

A 30 and 80 group sensitivity analysis for the overal tritium production in the tungsten based ASCB blanket was performed using the one-dimensional sensitivity code SENSIT.[17] It is interesting to notice that in the 30 neutron group structure iron resonances lie in groups 15 - 20, whereas in the 80 group structure they are spread between groups 20 to 65. Tungsten resonances are located at lower energies (i. e. groups 20 - 25 in the 30 group structure, and groups 69 - 73 in the 80 neutron group library).

Finally all Monte Carlo calculations were performed with the MCNP code , following 10,000 particle histories.

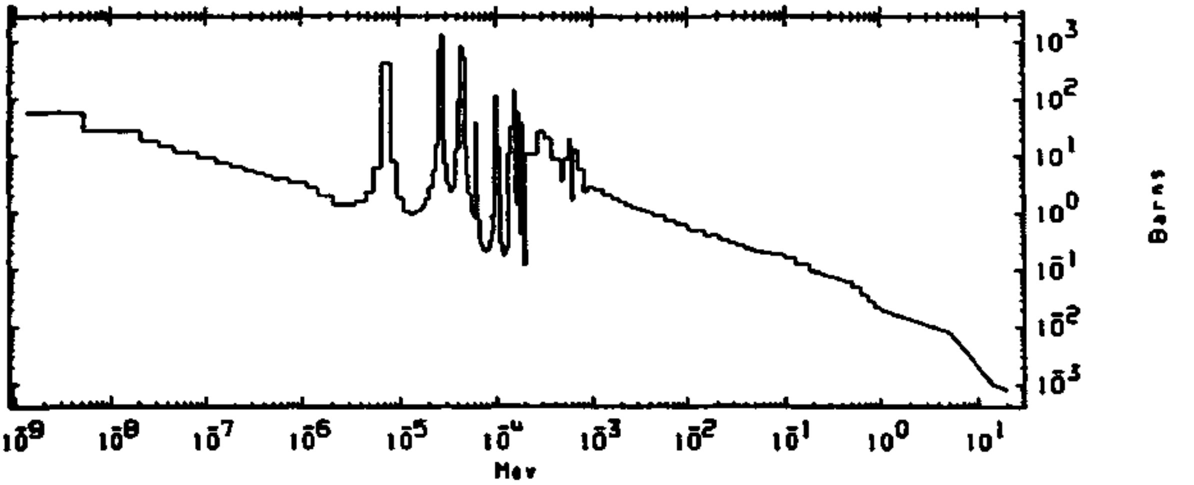


Figure 3: Capture cross sections of ^{182}W

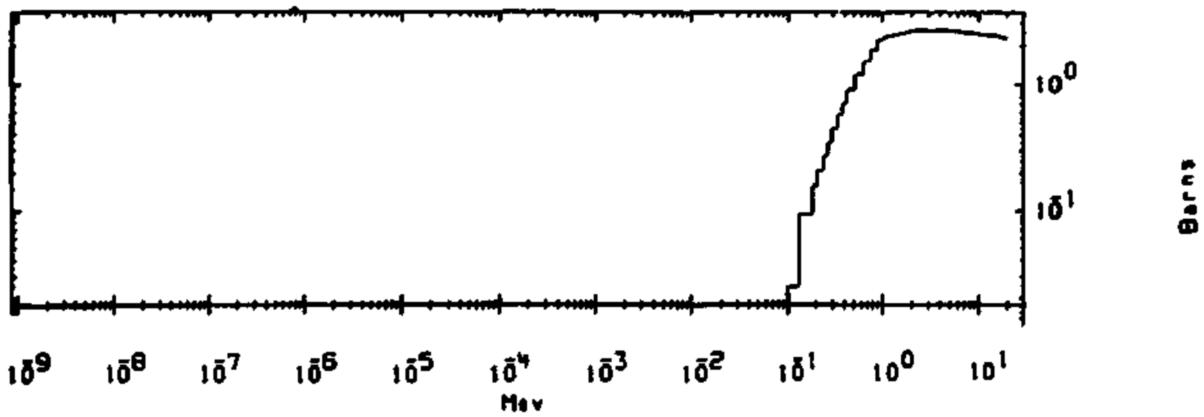


Figure 4: (n,2n) and (n,3n) cross sections of ^{182}W

Table I: GEOMETRICAL MODEL OF THE STEEL ASCB DESIGN

ZONE	OUTER RADIUS (cm)	MATERIALS	ATOMIC DENSITY (1.0E-24/cm^3)
PLASMA	96.90	Vacuum	
VACUUM	148.90	Vacuum	
FIRST WALL:	150.35	Ni	7.344E-3
73.69% SS316L		Cr	1.185E-2
26.61% H_2O		C	8.791E-5
		Fe	4.036E-2
		H	1.759E-2
		O	8.795E-3
BLANKET:	166.35	Ni	7.475E-3
75% SS316L		Cr	1.208E-2
10% AQ SOL		C	8.948E-5
AQ SOL = H_2O		Fe	4.108E-2
+10 g ^{6}LiOH		H	1.737E-2
/ 100 cc H_2O			
		O	9.012E-3
		^{6}Li	6.550E-4
SHIELD:	200.00	Ni	7.973E-3
80% SS316L		Cr	1.286E-2
20% H_2O		C	1.544E-5
		Fe	4.382E-2
		H	1.837E-2
		O	6.686E-3

Table II: GEOMETRICAL MODEL OF THE TUNGSTEN ASCB DESIGN

ZONE	OUTER RADIUS (cm)	MATERIALS	ATOMIC DENSITY (1.0E-24/cm^3)
PLASMA	85.00	Vacuum	
VACUUM	96.50	Vacuum	
SHIELDING	145.90	^{182}W	1.120E-2
BLANKET		^{183}W	6.142E-3
75% W (90% t.d.) +		^{184}W	1.310E-2
10% PCA + 15%		^{186}W	1.222E-2
H_2O+10 g ^{6}LiOH		Fe	5.499E-3
per 100 cc H_2O)		Ni	1.290E-3
		Cr	1.274E-3
		^{55}Mn	1.700E-4
		Mo	9.900E-5
		^6Li	3.930E-4
		H	1.036E-2
		O	5.407E-3
SHIELD	149.40	^{10}B	1.589E-3
(85% B_4C (86% T.D.) +		^{11}B	6.337E-2
10% PCA + 5% (H_2O +		C	2.007E-2
10 g ^{6}Li / 100 cc H_2O))		Fe	5.499E-3
		Ni	1.290E-3
		Cr	1.274E-3
		^{55}Mn	1.700E-4
		Mo	9.900E-5
		^6Li	1.310E-4
		H	3.454E-3
		O	1.802E-3
CLEARANCE	151.40	Vacuum	
TF-COIL	200.00	Cu	8.490E-2

4 COMPUTATIONAL RESULTS

Table III shows the results pertaining to the homogeneous stainless steel based ASCB blanket indicative for NET. Computations were performed using MCNP and the related RMCCS and DRMCCS libraries, and ONEDANT together with self-shielded and infinite dilute MATXS6 and EFF- 1/VITAMIN-J cross sections.

The conclusions from the results in table III can be summarized in the following points:

1. Self shielding of resonance cross sections results in a minor increase in the tritium breeding ratio of less than 1 percent (0.608 versus 0.603 in the VITAMIN-J case, 0.597 versus 0.594 in the MATXS6 case). The neutron spectrum is soft, and its relevant part lies below structural material resonances (see Figs. 5-7), explaining the absence of self-shielding effects. The iron resonances are involved in the slowing-down process of the neutrons. The spectrum itself is determined by the high density moderating materials, such as hydrogen, oxygen and lithium. About 80 percent of the total tritium production is found to be contributed at energies less than 1 KeV, and no self shielding occurs in the first wall materials.

2. Good agreement (within 1 percent) is found between the MCNP Monte Carlo and the discrete-ordinates method. This confirms previous studies where similar soft spectra originated.[7] Capture rates in structural material which agree well in all different computations are lower compared to tritium breeding. A relatively thick shield (see Table I) will therefore be required with this blanket option.

3. Good agreement within 1 percent is achieved in all important reaction rates between ENDF/B-V and EFF-1 data. This proves the adequacy of both evaluations in estimating soft fusion spectra. The calculated performance of such blankets is found to be almost independent on the number of groups used.[7] Furthermore, threshold reactions are not affected by self-shielding effects, which is consistent with previous studies.[7]

Table IV shows the results pertaining to the NET blanket described with some heterogeneous models. To study the heterogeneity effects the blanket was first subdivided into four zones of the same volume consisting of alternate regions of aqueous solution and stainless steel and vice versa. A second approach dealt with 8 regions of the same volume and composition. The aim of such an investigation is to enhance the tritium breeding ratio through multiplicative reactions within the heterogeneous distribution of structural material. All computations were performed with self- shielded and infinite dilute MATXS6 ENDF/B-V data, and the ONEDANT code. Table IV shows that no relevant enhancement of the tritium breeding ratio (only about 2 percent) can be achieved in this way.

This is because the neutron spectrum is still dominated by light isotopes such as H, O, ^{6}Li (see Fig. 7). If the aqueous solution is posted in front of the plasma almost all neutrons are slowed down by the water. Furthermore 25 percent of this neutron population is found to be already absorbed by ^{6}Li in this region. If stainless steel is posted in front of the plasma the

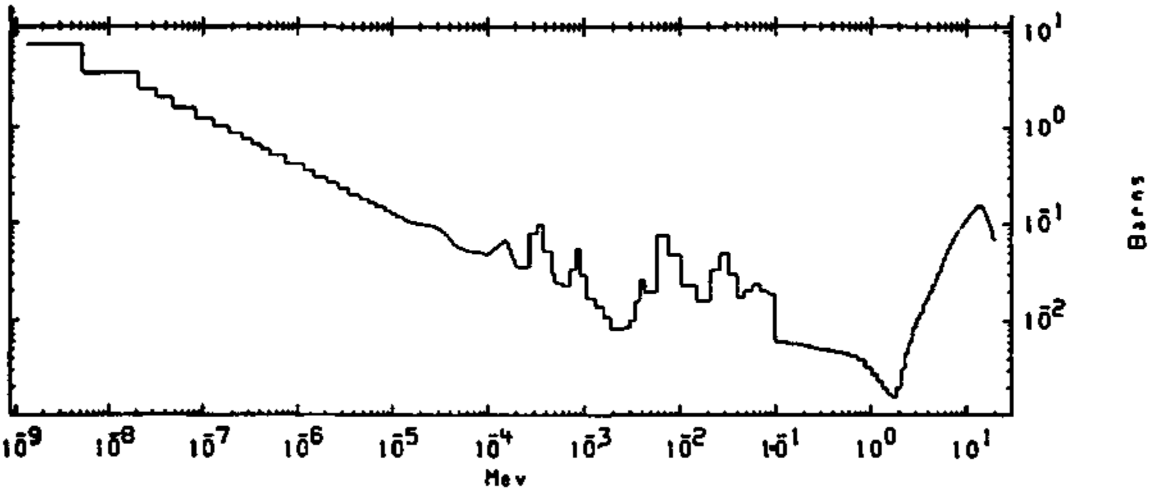


Figure 5: Fe Capture Cross Sections

situation does not change. Fe (n,2n) and Fe(n,γ) rates are practically equivalent and very small in magnitude (i.e. 0.0932 versus 0.0894) so that the structural material is mainly transparent for the fast neutrons resulting from the fusion process. This can be easily explained by comparing Fig. 5 with Fig. 6. It is evident that increasing the number of heterogeneous zones within the breeding blanket tends to reproduce the homogeneous results (see Table III).

Table V shows the results pertaining to the homogeneous tungsten based TIBER-II inboard blanket. Computations were performed using MCNP and the related RMCCS and DRMCCS libraries, and ONEDANT with self-shielded and infinitely dilute MATXS6 based cross sections. Following comments can be deduced:

1. Good agreement within 3 percent is achieved for all reaction rates between the discrete MCNP calculation and the ONEDANT infinite dilute calculation. This was already pointed out in previous studies in the case of similar concepts.[7]

2. The self shielding of resonance cross sections nearly doubles the calculated tritium breeding ratio (TBR), changing it from about 0.05 for the infinitely dilute case to 0.1 for the self-shielded calculations. The mechanics of self shielding effects of this nature have been explained previously.[7] Note that even though the effects of self shielding are very pronounced for this blanket (in the homogeneous mode), the absolute value of the tritium breeding ratio, 0.1, is very modest. The presence of self-shielding effects can be explained with similar arguments that were used for indicating the absense of self shielding in the iron based ASCB blanket. The main difference here relates to the fact that tungsten resonances absorb water moderated neutrons well, which results in high capture rates within the structural material (i.e. 1.63 in the continuous MCNP calculation). This is because tungsten resonance cross sections are much higher than iron resonance cross sections (in average two orders of magnitude difference, see Figs. 1-5). Furthermore tungsten resonances lie at lower energies (i.e. between 3 eV and 4000 eV) where the water moderated

Table III: IMPORTANT REACTION RATES OF A HOMOGENEOUS STAINLESS STEEL ASCB BLANKET COMPUTED USING DIFFERENT METHODS AND DATA LIBRARIES

	$^6Li(n,\alpha)T$	SS316(n,γ)	SS316L(n,2n)
MCNP Continuous	0.5770 ±1%	0.1888 ±1%	0.1498 ±1%
MCNP discrete	0.5667 ±1%	0.1913 ±1%	0.1506 ±1%
MATXS6 self-shielded	0.5970	0.1957	0.1616
MATXS6 infinitely dilute	0.5940	0.2030	0.1616
VITAMIN-J self-shielded	0.6084	0.1930	0.1639
VITAMIN-J infinitely dilute	0.6025	0.2013	0.1639

spectrum is relevant (see Fig. 8). 70 percent of total tritium breeding is found to occur between 10 eV and 4000 eV. Besides the different resonance behavior, the same situation occurred in the stainless steel blanket.

3. In these particular types of aqueous self-cooled blankets the tungsten cross sections are almost fully shielded at high energies (i. e. 20 barns dilution cross section in the MeV and keV, and up to 5000 barns in the keV to eV range). Since in MATXS6 data are tabulated down to 100 barns, an additional background cross section term (arising from the reduction of the mean chord length of the breeding blanket) had to be added into the breeding blanket cross sections in order to avoid divergence in the TRANSX-CTR calculation.

Table V shows however that the discrete-ordinates calculation overestimates the self-shielding effect due to the too large extrapolation onto low background cross sections. The assumptions of energy independent sigma zero values of 100 and 1000 barns for tungsten isotopes respectively with the correct escape probability show that the MCNP continuous calculation gives a reasonable estimate of the self-shielding effect in the homogeneous approximation.

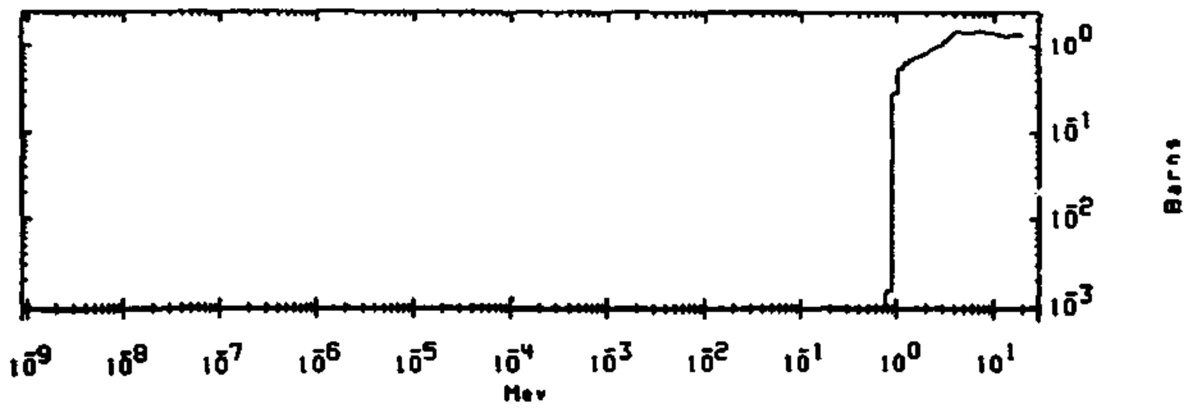


Figure 6: Fe (n,2n) cross sections

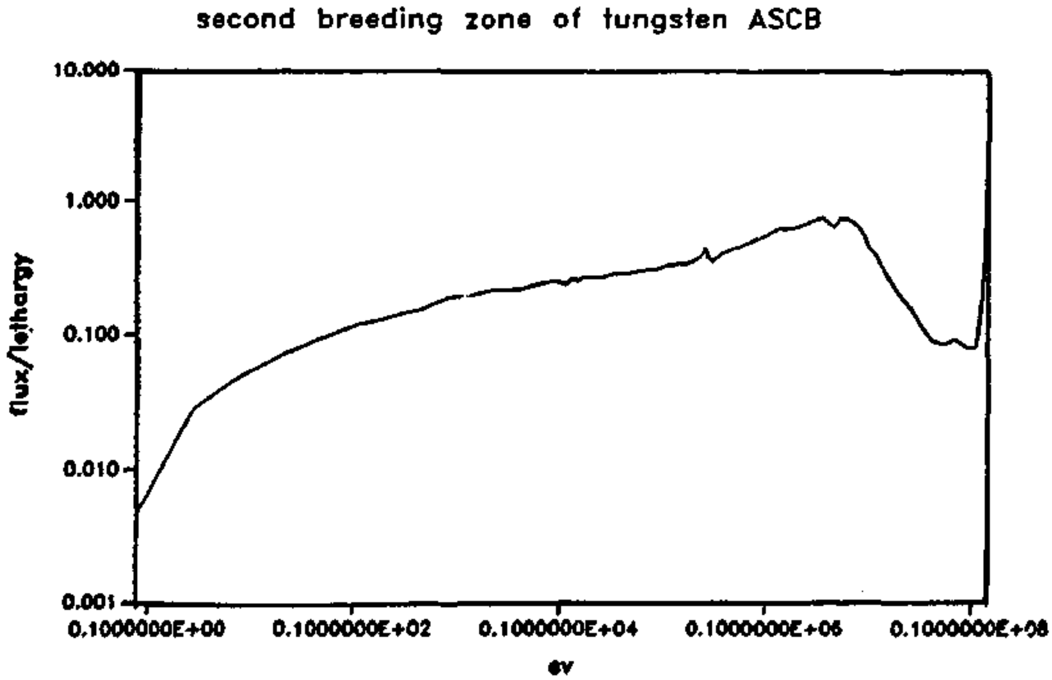


Figure 7: Neutron flux expressed per unit of lethargy in the ASCB breeding blanket of the SS316L reference concept, computed using ONEDANT and the infinitely dilute MATXS6 based cross section library (Homogeneous Model).

Table IV: IMPORTANT REACTION RATES IN THE MAIN BREEDING ZONE OF THE HETEROGENEOUS SS316 ASCB BLANKET ESTIMATED USING MATXS6 SELF-SHIELDED AND INFINITELY DILUTE DATA

		$^6Li(n,\alpha)T$	SS316(n,γ)	SS316L(n,2n)
Model 1	inf. dilute	0.6100	0.1648	0.1516
1 zone	self shielded	0.6115	0.1584	0.1516
of A, S*				
Model 2	inf. dilute	0.5856	0.2137	0.1720
4 zones	self shielded	0.5904	0.2030	0.1719
of S, A				
Model 3	inf. dilute	0.6052	0.1565	0.1791
8 zones	self shielded	0.6071	0.1565	0.1725
of A, S				

* A means aqueous solution region (i.e. H_2O + 10 g ^6LiOH per 100 cc H_2O)
S means SS316L

Figure 8: Comparison of neutron fluxes for tungsten inboard design in the breeding blanket (homogeneous versus heterogeneous modelling).

Table VI shows the results pertaining to the heterogeneous tungsten based inboard blanket. Computations were performed using MCNP, the related RMCCS and DRMCSS ENDF/B-V libraries, and ONEDANT with self-shielded and infinitely dilute MATXS6 based cross sections. The blanket was first subdivided into 4 zones of the same volume consisting of alternating slabs of tungsten, PCASS, aqueous solution regions and then of aqueous solution, tungsten and PCASS regions respectively. Second, the blanket was subdivided into 8 cylindrical zones of 3 regions each. Similar analyses were already performed[6] for a tungsten based aqueous self-cooled shielding blanket. However no self-shielding effect of the resonance cross sections was included in this study.

The main points that can be concluded from table VI were previously observed by Cheng and Pelloni.[7] In contrast to the stainless steel case, tungsten acts as a good neutron multiplier for fast neutrons (see Fig. 4) and as an absorber for water moderated epithermal neutrons (see Fig. 3). Thus a large effect on the tritium breeding ratio can be seen when the heterogeneous design option is compared to the homogeneous one (Fig. 8). A tritium breeding ratio as high as 0.66 can be achieved when the aqueous solution is located just behind the plasma (there is no first wall in this idealized representation). This is a significantly different value for the TBR when compared to the 0.08 that resulted from self-shielded homogenized calculations (Table V). A doubled breeding rate than in the stainless steel blanket (about 0.4) can be achieved in the first thick aqueous zone, in which ^{6}Li is now saturated. Thus tungsten (n,2n) reaction enhances tritium breeding in the second zone through the remaining fast MeV neutrons. As far as the self shielding of resonance cross sections is concerned, this results in a maximum increase of about 5 percent in the tritium breeding ratio, depending on the selected model for including the heterogeneity effects.

This effect is less pronounced in its magnitude when the tritium breeding ratio increases because less neutrons are in that case available for absorption in the resonance region (compare homogeneous model with model 1 and model 2 of Table VI). At this point it is worthwhile noticing that the TRANSX-CTR calculations could be performed successfully in the self-shielded

Table V: IMPORTANT REACTION RATES OF HOMOGENEOUS TUNGSTEN BASED ASCB INBOARD DRIVER BLANKET COMPUTED USING ENDF/B-V DATA LIBRARIES

^{6}Li(n,α)T	W(n,γ)	W(n,2n)	
MCNP continuous	0.0840 ±1.1%	1.6277 ±0.5%	0.7491 ±1%
MCNP discrete	0.0472 ±0.9%	1.6822 ±0.4%	0.7484 ±1.0%
MATXS6 self shielded[a]	0.1006	1.6117	0.7483
MATXS6 inf. dilute	0.0456	1.6787	0.7483
MATXS6[b]	0.1056	1.6070	0.7483
MATXS6[c]	0.0616	1.6618	0.7483

[a] with enlarged escape cross section from the blanket (mean chord length of 1cm) to avoid diverging extrapolation, hereby overestimating self-shielding effects

[b] ^{182}W - ^{186}W taken at 100 barns dilution cross section

[c] ^{182}W - ^{186}W taken at 1000 barns dilution cross section

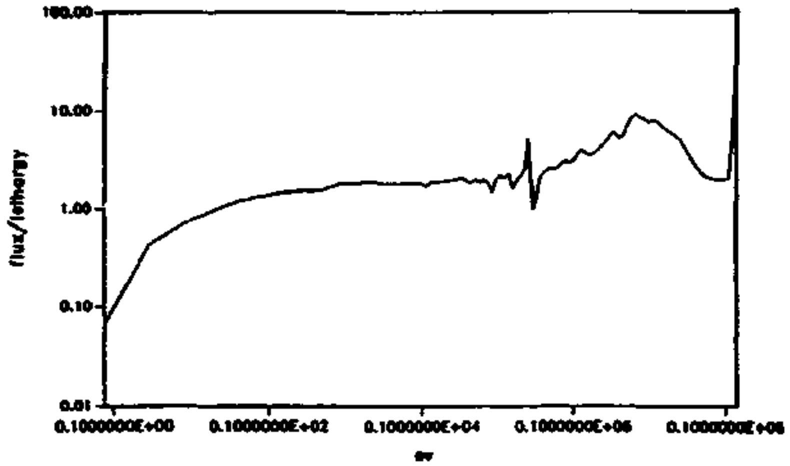


Figure 9: Neutron flux expressed per unit lethargy in the tungsten based aqueous self-cooled breeding blanket (heterogeneous) based on ONEDANT and the MATXS6 infinitely dilute library.

case, due to the smaller mean chord length, resulting in larger background cross sections (compare the case with 100 barn dilution cross sections of Table VI). Neutron spectra in this blanket in the case of model 2 are plotted in Fig. 9. The same kinds of consideration as those obtained from Fig. 8 can be applied. Again the results from the multi-heterogeneous model tend to reproduce the homogeneous results. The MCNP results in the case of model 2 show again good agreement with the discrete-ordinates calculations. However due to statistical errors in the tritium breeding ratio no self-shielding effects can be observed.

5 SENSITIVITY ANALYSIS

A cross section sensitivity analysis for the tungsten based ASCB blanket was performed using the SENSIT code. Such an analysis requires a forward and adjoint calculation. The sensitivity of the tritium breeding ratio with respect to the elements in the blanket region was analyzed. The sensitivity analysis was done for an 80 as well as for a 30 group structure. The 80 group calculations are based on infinitely dilute cross sections. The tritium breeding ratios obtained from the forward and adjoint calculations are reproduced in table VII. From table VII can be concluded that the adjoint results are in excellent agreement with the direct results. The 80 group infinitely dilute calculations are about 5 percent different from the 30 group infinitely dilute calculation. Self-shielding effects more than double the calculated tritium breeding ratio. The direct term is not yet included in the sensitivity profiles, because of an anomaly in the SENSIT code, but will be included in further reporting on this work.

The integral loss and gain term, and the integral sensitivity for the elements in the blanket region are summarized in table VIII. The 80 group results (infinitely dilute) are also reproduced in this table (but between brackets). A detailed groupwise representation of the sensitivity results did not further contribute to our understanding, and was therefore not reproduced in this document. The detailed results from the 30 group analysis for the tungsten cross section are reproduced in table IX. A clear interpretation of table VIII emerges when we take into

Table VI: IMPORTANT REACTION RATES OF A HETEROGENEOUS TUNGSTEN BASED ASCB INBOARD BLANKET ESTIMATED USING ENDF/B-V SELF-SHIELDED AND INFINITELY DILUTE DATA

		^{6}Li(n,α)T	W(n,γ)	W(n,2n)
Model 1	inf. dilute[a]	0.6315	1.0152	0.6919
4 Zones	self shielded	0.6608	0.9841	0.6919
of A, W, P[b]				
Model 2	inf. dilute	0.3920	1.4446	0.8670
4 zones	self shielded	0.4190	1.4213	0.8678
of W, P, A	self shielded[c]	0.4192	1.4213	0.8678
MCNP RMCCS	0.4300	1.4105	0.8885	
	±1.4%	±0.5%	±1%	
MCNP DRMCCS	0.4307	1.4309	0.8892	
	±1.4%	±0.5%	±0.9%	
Model 3	inf. dilute	0.3165	1.3785	0.7319
8 zones				
of A, W, P				
Model 4	inf. dilute	0.2256	1.5604	0.8179
8 zones				
of W, P, A				

[a] MATXS6 based nuclear data

[b] A means aqueous solution region (i.e. H_2O + 10 g ^{6}LiOH/100 cc H_2O)

W means tungsten (at 90 % theoretical density)

P means PCASS (Primary Candidate Alloy Stainless Steel) region

[c] W at 100 barns dilution XS

Table VII: TBRs FROM DIRECT AND ADJOINT CALCULATIONS TUNGSTEN BASED ASCB INBOARD BLANKET

CASE	DIRECT MODE	ADJOINT MODE
30 Group	0.043061	0.043057
80 Group	0.045604	0.045595
80 Group self shielded	0.1006	

account for the fact that the integral sensitivity can be interpreted as the percentage change of the design parameter of interest (in our case the tritium breeding ratio in the blanket region) resulting from a simultaneous one percent increase of the group cross sections in all groups. These data can therefore also to a first degree being interpreted as the fractional uncertainty in the response function assuming that all the cross sections have a one percent uncertainty. The largest uncertainties are due to the tungsten and hydrogen cross sections (62.2 percent and 26.2 percent respectively). The large value of this uncertainty is not as surprising as we would expect from this first glance, when noticing that the tritium production rate in the blanket is only about 0.044. The (n,2n) and absorption rates in the tungsten are about 20 to 30 times larger, so that the large uncertainty in the tritium production rate is not surprising at all. The pronounced uncertainty due to the hydrogen cross sections can be explained when we account for the difference in the resonance absorption in the tungsten resonances when the scattering behavior of hydrogen is altered. Note that the sensitivities from the 30 and 80 group (not self shielded) calculations agree fairly well. We would expect these sensitivities and uncertainties to decrease by a factor of 2 for the 80 group self-shielded analysis, because of the fact that these results are normalized with respect to the response function. And the response function, in this case the tritium production rate in the blanket would increase from 0.046 to 0.1006 for the self-shielded analysis. A more realistic idea about the uncertainties in the tritium production rate could be obtained by repeating this analysis for a heterogeneous blanket representation. Because of the significantly higher tritium production rates involved with the heterogeneous representation, we would expect the sensitivities and associated uncertainties to decrease accordingly.

6 CONCLUSIONS

From the study presented in this report several conclusions and recommendations can be made. First, for water moderated blankets with iron as the structural material, no enhancement of the tritium breeding ratio can be observed if self-shielded resonance cross sections are utilized in the analysis. If the iron is replaced by tungsten self-shielding effects become relevant in a homogeneous analysis, however the obtained tritium production rates are so low that this conclusion does not lead to a practical application of this effect. Including heterogeneity effects in the analysis leads to substantially higher tritium production rates, and marginal self-shielding effects can be observed (on the order of 5 %). From the sensitivity analysis can be concluded that the uncertainties in the tungsten cross section lead to a large uncertainty in the tritium production rate. These uncertainties decrease when the tritium production rate increases, but remain significant nevertheless.

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Table VIII: INTEGRAL SENSITIVITY FOR THE TRITIUM BREEDING RATIO FOR A TUNGSTEN BASED ASCB FOR 30 (AND 80) NEUTRON GROUPS

ELEMENT	LOSS TERM (TXS)	GAIN TERM (NGAIN)	NET SENSITIVITY (SENT)
W	-19.1 (-18.2)	18.5 (17.5)	-0.622 (-0.710)
^{6}Li	-0.0678 (-0.0770)	0.0283 (0.0250)	-0.0395 (-0.0520)
Fe	-1.131 (-1.090)	1.105 (1.060)	-0.0260 (-0.0273)
Ni	-0.450 (-0.462)	0.439 (0.450)	-0.0106 (-0.0120)
Cr	-0.280 (-0.275)	0.274 (0.268)	-0.00621 (-0.00692)
^{55}Mn	-0.0933 (-0.107)	0.0930 (0.106)	-0.00119 (-0.00128)
Mo	-0.0332 (-0.0317)	0.0324 (0.0309)	-0.000725 (-0.000781)
^{1}H	-4.272 (-3.22)	4.009 (3.06)	-0.262 (-0.156)
^{16}O	-0.881 (-0.814)	0.857 (0.789)	-0.0239 (-0.0250)

Table IX: SENSITIVITY PROFILE OUTPUT FOR W (30 GRPS)

DEFINITIONS OF SENSITIVITY PROFILE NOMENCLATURE

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axs = sensitivity profile per delta-u for the absorption cross -section(taken from position iha in input cross-section tables), pure loss term

sxs = partial sensitivity profile per delta-u for the scattering cross-section (computed for each energy group as a diagonal sum from input xs-tables), loss term only

txs = sensitivity profile per delta-u for the total cross section (as given in position iht in input cross-section tables), pure loss term

n-gain = partial sensitivity profile per delta-u for the neutron scattering cross-section. gain term for sensitivity gains due to scattering out of energy group g into all lower neutron energy groups, computed from forward difference formulation.

sen = net sensitivity profile per delta-u for the scattering cross-section (sen = sxs + ngain)

sent = net sensitivity profile per delta-u for the total cross-section (sent=txs+ngain)

***************** SUMMED OVER ALL PERTURBED ZONES ********************

PARTIAL AND NET SENSITIVITY PROFILES PER DELTA-U, NORMALIZED TO THE RESPONSE (r,phi) = 9.77383e 02
FOR NEUTRON INTERACTION CROSS SECTIONS: (n-n) and (n-gamma)

Table IX: SENSITIVITY PROFILE OUTPUT FOR W (30 GRPS) (continued)

			PURE LOSS TERMS			GAIN	NET PROF.	
group	upper-e	delta-u	AXS	SXS	TXS	N-GAIN	SEN	SENT
1	1.700e 07	1.25e-01	0.000e 00	0.000e 00	0.000e 00	0.000e 00	0.000e 00	0.000e 0
2	1.500e 07	1.05e-01	6.955e 00	-1.791e 01	-1.095e 01	1.156e 01	-6.346e 00	6.088e-1
3	1.350e 07	1.18e-01	2.148e-01	-5.649e-01	-3.501e-01	3.718e-01	-1.932e-01	2.170e-2
4	1.200e 07	1.82e-01	4.850e-02	-1.351e-01	-8.661e-02	9.244e-02	-4.267e-02	5.830e-3
5	1.000e 07	2.50e-01	1.610e-02	-6.984e-02	-5.374e-02	5.641e-02	-1.344e-02	2.662e-3
6	7.790e 06	2.49e-01	1.392e-03	-5.971e-02	-5.832e-02	5.887e-02	-8.412e-04	5.513e-4
7	6.070e 06	5.00e-01	2.208e-04	-1.536e-01	-1.538e-01	1.536e-01	-3.173e-05	-2.525e-4
8	3.680e 06	2.50e-01	-1.058e-03	-3.999e-01	-4.009e-01	3.985e-01	-1.334e-03	-2.392e-3
9	2.865e 06	2.50e-01	-2.871e-03	-6.817e-01	-6.846e-01	6.788e-01	-2.916e-03	-5.784e-3
10	2.232e 06	2.50e-01	-5.738e-03	-1.003e 00	-1.009e 00	1.000e 00	-3.055e-03	-8.796e-3
11	1.738e 06	2.50e-01	-9.853e-03	-1.412e 00	-1.421e 00	1.409e 00	-2.282e-03	-1.213e-2
12	1.353e 06	4.97e-01	-1.894e-02	-2.283e 00	-2.302e 00	2.281e 00	-1.589e-03	-2.054e-2
13	8.230e 05	4.98e-01	-2.699e-02	-3.126e 00	-3.153e 00	3.133e 00	7.191e-03	-1.980e-2
14	5.000e 05	5.01e-01	-2.873e-02	-3.133e 00	-3.162e 00	3.137e 00	3.939e-03	-2.479e-2
15	3.030e 05	4.99e-01	-3.131e-02	-2.861e 00	-2.892e 00	2.784e 00	-7.701e-02	-1.083e-1
16	1.840e 05	1.00e 00	-3.193e-02	-2.049e 00	-2.081e 00	2.045e 00	-3.835e-03	-3.576e-2
17	6.760e 04	1.00e 00	-3.388e-02	-1.818e 00	-1.852e 00	1.818e 00	-7.353e-04	-3.462e-2
18	2.480e 04	1.00e 00	-4.253e-02	-1.667e 00	-1.710e 00	1.666e 00	-1.053e-03	-4.368e-2
19	9.120e 03	1.00e 00	-6.522e-02	-1.658e 00	-1.723e 00	1.657e 00	-1.397e-03	-6.662e-2
20	3.350e 03	9.98e-01	-9.456e-02	-1.412e 00	-1.506e 00	1.411e 00	-8.100e-04	-9.537e-2
21	1.235e 03	1.00e 00	-1.013e-01	-1.026e 00	-1.128e 00	1.026e 00	-2.478e-04	-1.016e-1
22	4.540e 02	9.48e-01	-7.977e-02	-6.518e-01	-7.316e-01	6.522e-01	4.254e-04	-7.935e-2
23	1.760e 02	1.05e 00	-5.745e-02	-2.351e-01	-2.925e-01	2.347e-01	-3.524e-04	-5.780e-2
24	6.140e 01	9.99e-01	-2.307e-02	-4.022e-02	-6.329e-02	3.979e-02	-4.342e-04	-2.350e-2
25	2.260e 01	9.99e-01	-4.068e-03	-1.703e-02	-2.110e-02	1.703e-02	4.715e-06	-4.064e-3
26	8.320e 00	1.00e 00	-5.566e-03	-4.550e-04	-6.021e-03	4.988e-04	4.382e-05	-5.522e-3
27	3.060e 00	9.98e-01	-1.744e-02	-2.482e-02	-4.226e-02	2.486e-02	4.1[illegible]7e-05	-1.740e-2
28	1.130e 00	1.00e 00	-1.298e-02	-1.637e-02	-2.935e-02	1.638e-02	5.889e-06	-1.298e-2
29	4.140e-01	1.00e 00	-8.954e-03	-7.387e-03	-1.634e-02	7.388e-03	1.245e-06	-8.953e-3
30	1.520e-01	1.11e 00	-9.436e-03	-2.856e-03	-1.229e-02	2.856e-03	2.600e-08	-9.436e-3
INTEGRAL			1.252e-01	-1.926e 01	-1.914e 01	1.852e 01	-7.471e-01	-6.220e-1

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