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HOTSPUR Progress Report: Neutron Source
Spectrum Characterization, and ${}^6\text{Li}(n,\alpha)$
and ${}^7\text{Li}(n,\alpha)$ Cross Section Determination

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Abstract

As a prerequisite to high accuracy measurements involving the bulk configuration of ${}^6\text{LiD}$ we must have a good grasp of the details of the RTNS-I neutron source energy spectrum. Experiments to this end involving neutron yield vs deuteron energy, ratios of foil activation of selected elements, and pulse height distributions of a Si surface barrier detector are described. With this knowledge, the ${}^4\text{He}$ -production cross sections for ${}^6\text{Li}$ and ${}^7\text{Li}$ are found experimentally to be 0.512b and 0.336b, respectively, at $E_N = 15.0$ MeV in free-field geometry.

Introduction

Ten runs have been conducted at RTNS-I since September of 1982 to determine the spatial character of tritium and ${}^4\text{He}$ production in a bulk configuration of ${}^6\text{LiD}$ under bombardment with D-T neutrons. These are briefly summarized in Table I. Previous memoranda^(1,2) dealt with findings from the first five and laid ground for the final thrust. We will concentrate in the present note on the examination of the runs of April 27, 1983 and August 4, 1983, deferring the bulk measurements to a separate report.

¹Unclassified memo of Dec. 16, 1982: "HOTSPUR: Exposure of Samples Containing ${}^6\text{Li}$ to RTNS-I Neutrons ...", E. Goldberg and R. C. Haight

²Unclassified Memo of April 26, 1983: "HOTSPUR Progress Report: Preparations for Bulk Measurements ...", E. Goldberg and R. C. Haight

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Table I. Chronology of Hotspur Runs at RTNS-I Facility

- 9/28/82 Shakedown run: $\sigma_6(n, \alpha) \sim 520$ mb (R-I Capsules)
- 11/3/82 Neutron source strength, angular dependence ($dY/d\Omega$)
- 1/19/83 Improved ($dY/d\Omega$); $\sigma_6(n, xT) \sim 25$ mb
- 3/8/83 First use of Li/Pb capsules; cross-calibration of radchem foils
- 3/29/83 Reflection correction for PRC's: 11%; large ^6LiD cylinders used
- 4/27/83 Neutron source study: $\bar{E}_N \sim 14.9\text{--}15.0$ MeV; $Y(E_b)$, Si surface barrier detector, radchem ratios
- 6/1-4/83 First bulk measurement: $Y_{6,7}(n, \alpha)$, $Y_{6,7}(n, xT)$; $S \sim 3.0 \times 10^{17}n$
- 8/4/83 Free-Field ^4He measurement: $\sigma_6(n, \alpha) = 512$ mb, $\sigma_7(n, \alpha) = 336$ mb
- 9/21-9/24/83 Second bulk measurement: $Y_{6,7}(n, \alpha)$, $Y_{6,7}(n, xT)$; $S \sim 5.0 \times 10^{17}n$
- (11/8/83) Free-Field Tritium measurement; $\sigma_{6,7}(n, xT)$

As the program progressed, it has become clear that the source fluence is best determined from activation foils. The RTNS-I facility's proton-recoil counter capability for accurate fluence measure is seriously degraded by the reflection of neutrons by the ^6LiD bulk configuration.⁽²⁾ Our primary standard is then the $^{27}\text{Al}(n, \alpha)^{24}\text{Na}$ reaction. Since the half-life of ^{24}Na is 15.0 hours, we utilize the reactions $^{93}\text{Nb}(n, 2n)^{92m}\text{Nb}$ and $^{197}\text{Au}(n, 2n)^{196}\text{Au}$ for runs of longer duration with cross sections found in reference to the $^{27}\text{Al}(n, \alpha)^{24}\text{Na}$ values.⁽²⁾ The latter is markedly energy-dependent, and so we are required to know the neutron energy spectrum approximately and the average energy with fair accuracy. An uncertainty in $\bar{E}_n$ of 100 keV implies an uncertainty in cross section (and therefore fluence) of

1.5-2%. With knowledge of source spectrum and strength in hand, we are able to interpret the free-field findings of the August 4 run and generate ^4He -production cross sections.

Neutron Source Spectrum

A. Neutron Yield vs E_0

Seagrave⁽³⁾ and Benveniste⁽⁴⁾ calculated for a thick tritiated titanium target neutron energy spectra from the D-T reaction for various deuteron energies and at different angles of emergence assuming a target composition of TiT (although the stoichiometric form is TiT_2). An early examination of RTNS-I targets by Booth and Barschall indicated a ratio of tritium to titanium of 1.3,⁽⁵⁾ for a fresh target. (More precisely, the Seagrave curve for neutron yield vs E_0 was multiplied by 1.3 to agree with experiment.) In the early 70's the electronic stopping cross sections of deuterium in titanium were carefully measured⁽⁶⁾ and found to be ~ 40% higher than values used in the calculations of Refs. 4 and 5. [The higher Ti values are incorporated in present accepted stopping cross section compilations⁽⁷⁾.]

³ J. D. Seagrave, Los Alamos Report LAMS 2162 (1958)

⁴ J. Benveniste and J. Zenger, Lawrence Rad. Lab, Livermore Report UCRL-4266 (1954)

⁵ R. Booth and H. H. Barschall, Nuc. Inst. and Meth. 99 (1972)1.

⁶ J. H. Ormrod, Nuc. Inst. and Meth. 95 (1971)49.

⁷ H. H. Andersen and J. F. Ziegler (1977) Hydrogen Stopping Powers and Ranges in All Elements, vol. 3 of The Stopping and Ranges of Ions in Matter, organized by J. F. Ziegler (New York: Pergamon)

During the run of April 27, 1983, we investigated the behavior of the mounted target which was moderately aged (~ 248 ma-hr on the band employed). The measurements were hastily made, with no special effort taken to insure suppression of secondary electrons. These results should not be taken as definitive, but rather suggestive. Figure 1 compares the experimental results to expectations. The Seagrave curve is taken from Ref. 3. Based on the more recent Ti data of Ormrod⁶ and assuming a composition of $\text{TiTi}_{1.5}$, we generate a curve seen in Fig. 1 which is very similar to Seagrave's. It also follows that the experience of Booth and Barschall suggests that their target was $\text{TiTi}_{(1.3 \times 1.5)}$, or $\sim \text{TiTi}_2$ which is stoichiometrically allowed.

The experimental points indicated a lesser sensitivity of neutron average energy to deuteron energy than the simple model. Several spatial profiles were assumed to generate Y vs E_D values. One which gave good agreement with experiment is illustrated in Fig. 1. There we see a surface layer enriched to TiTi_2 while at depths greater than 0.2 mg/cm^2 , we have TiTi , which implies a depletion. This clearly rules out any evidence of surface depletion for the target studied. We note in passing that the range in $\text{TiTi}_{1.5}$ for $E_0 = 400 \text{ keV}$ is $\sim 1.2 \text{ mg/cm}^2$. This range is insensitive to the Ti:T ratio since energy loss to Ti dominates. The effect of surface enrichment, exemplified by the tritium profile of Fig. 1, is seen to have a modest effect on $\bar{E}_n$. For $\theta = 0^\circ$, the average neutron energy, $\bar{E}_n$, is increased by $\sim 50 \text{ keV}$ for the profile inferred from information of Fig. 1. The Seagrave spectrum was used for the uniform loading reference calculation. We would then infer a value of:

$$\bar{E}_n (\theta = 0) = \bar{E}_{\text{Seagrave}} + .05 \approx 15.03 \text{ MeV}$$

FIGURE 1

NEUTRON YIELD PER STERADIAN
VS.
DEUTERON ENERGY

Foil Activation

A popular technique for determining $\bar{E}_n$ involves simultaneous exposure of two thin foils in contact so that both are exposed to the same fluence. If the foils are chosen so that the ratios of activation cross sections are strongly energy-dependent, one is then able to infer the $\bar{E}_n$ from the ratio of activation values. We exposed foils of Zr, Al, Nb, Au, and Ni, and find similar results from the various combinations. Since the cross sections for $Zr^{(8)}$ and $Al^{(9)}$ are best known, we will confine our discussion to the $^{90}Zr(n,2n)^{89}Zr / ^{27}Al(n,\alpha)^{24}Na$ ratio.

For the run of April 27, 1983, three sets of foils were exposed along the beam axis, at various distances. Correcting for the finite extent of the closer foils, we find

$$\bar{E}_n(\theta = 0)_{Zr:Al} = 14.95 \pm .04 \text{ MeV}$$

If we use the cross sections currently employed by Nethaway⁽¹⁰⁾ the corresponding number is found to be $14.92 \pm .03$ MeV. We recall the Seagrave value to be 14.98 MeV for a titanium-based fresh target, in good agreement with the Pavlik/Tagesen value. The value inferred from the Nb:Zr combination is 14.98 MeV while that from Nb:Al is 14.89 MeV, further reinforcing the Pavlik/Tagesen value.

⁸ A. Pavlik et al., J. Phys. G: Nucl. Phys. 8(1982) 1283.

⁹ S. Tagesen and H. Vonach, Physics Data 13-3(1981). (Karlsruhe)

¹⁰ For $^{27}Al(n,\alpha)^{24}Na$, private communication, D. R. Nethaway; for $^{90}Zr(n,2n)^{89}Zr$, "Geraldine set" from Nethaway

Si-Surface Barrier Detector

A surface barrier detector (1500 μ thick, 200 mm² area) was exercised during the April 27, 1983 run. Pulse-height distributions were recorded at 0°, 96°, 135° and 150°. The distribution at $\theta = 96^\circ$ bore a close resemblance to that found by Ryves and Zieba.⁽¹¹⁾ The technique is straightforward, and based on the fact that the pulse height is proportional to the energy deposited by the charged particles. At 96°, prominent peaks are recorded which correspond to the $^{28}\text{Si}(n, \alpha_i)^{25}\text{Mg}$ reactions with the ^{25}Mg going to its ground state or various excited states. The relation is simply:

$$E_n + Q = E_\alpha + E_{^{25}\text{Mg}} \quad (E_i = \text{Kinetic energy of particle})$$

The energy level structure of ^{25}Mg is well known, and the $(Q_0 - Q_4)$ is 1.9649 MeV. We are able then to establish our channel width. Knowing that $E_n = 14.00$ MeV at $\theta = 96^\circ$, we are able to attach an energy scale to the channel number.

Because $E_D \sim 400$ keV, the neutron spectra in the forward and backward directions have sizeable spreads and the pulse height spectra at angles far from 96° are not of crisp quality. For the $\theta = 0^\circ$ case, we find the spectrum peak at 14.85 MeV, compared to Seagrave's 14.80 MeV. However, the spectrum shape did not agree closely with that expected from Seagrave, because of a deterioration of resolution and rise in counts as the pulse height decreased and also because of the energy dependence of

¹¹ T. B. Ryves and K. J. Zieba, Nucl. Instr. Methods 167, 449-453 (1979)

the Si(n, α) cross sections. We can say conservatively that the energy values of distinguishing spectral features inferred from the Si detector agree within ± 100 keV with Seagrave's representation.

On the other hand, we found the Si detector to be an excellent monitor for changes in the neutron spectra as a D-T target deteriorated. To this end we emplaced the detector in subsequent runs at $\theta = 180^\circ$, approximately 3m from the source (against the pit wall), and concentrated on the portion of pulse-height spectrum corresponding to the $^{28}\text{Si}(n, \alpha_0)^{25}\text{Mg}$ peak. Our longest run, a bulk measurement, was conducted in the period: Sept. 21-23, 1983, and employed a fresh target at the outset. A total of 4.98×10^{12} neutrons was generated, with a run time of 66 hr. We found the (n, α_0) peak to remain stationary to within 50 keV which is to be expected, but more surprising to us was the observation that as a particular band aged, the (n, α_0) peak narrowed symmetrically. This suggests that surface depletion and deleterious end-of-track effects simultaneously occur, with the net affect that the mean neutron energy at backward angles (and equivalently at forward angles) does not change. This simplifies the task of neutron source description considerably. What we can say for targets behaving like that employed in the Sept. 21-23 run is that if the initial tritium profile for the Sept. 21 run is consistently reproduced, the mean neutron energy in the forward direction remains constant to within ± 50 keV as the target ages.

Choice of Neutron Energy Spectrum

The above findings are seen to be in good agreement with the Seagrave description for aged as well as fresh tritiated targets with $\bar{E}_n$ known to within ± 100 keV. This energy uncertainty implies an uncertainty of $\sim \pm 1.5\%$ in the $^{27}\text{Al}(n, \alpha)^{24}\text{Na}$ reaction cross section, which is acceptably low in the establishment of source strength. We will

therefore use the Seagrave description on our TART Monte Carlo calculations. Briefly summarized for $E_D = 400$ keV and $\theta_N = 0^\circ$, neutrons range from 14.05 MeV to 15.60 MeV, peaking at 14.8 MeV and with $E_N = 14.98$ MeV.

Measurement of ${}^6\text{Li}(n,\alpha)$ and ${}^7\text{Li}(n,\alpha)$ Cross Sections at $E_N = 15.0$ MeV

The definitive run for measurements of ${}^4\text{He}$ -production cross sections of ${}^6\text{Li}$ and ${}^7\text{Li}$ at $\bar{E}_N = 15.0$ MeV at RTNS-I was performed on August 4, 1983. The experiment was designed to facilitate careful comparison to TART calculations. The geometry is illustrated in Fig. 2A and 2B. The first is a simplified drawing while the second, an engineering drawing, gives much of the details. A mylar tube 0.01 cm thick with a 2.54 cm I.D. formed the housing for the assembly. Pb-walled capsules of ${}^6\text{Li}$ and ${}^7\text{Li}$ metal were positioned, generally in groups of three, at six axial stations. All were exposed to neutrons emitted from the target in the forward direction. The assembly axis was aimed to coincide with the beam axis. The capsules were positioned with their axis horizontal within Pb frames to facilitate alignment and ensure accurate definition of location with respect to the neutron source. The arrangement described was eventually analyzed using three-dimensional TART geometry as well as 2D.

Each group of three capsules and its frame was sandwiched between activation foils of 2.54 cm diameter. The order of placement is given in Table II. Nominal foil thicknesses, in mils, are: Au(2.0), Al(4.5), Nb(1.95), Zr(4.5), and Ni(9.9).

At position F1, a special packet of six Rockwell-International miniature capsules of the type discussed in Ref. 1, clustered within a Pb cylindrical tube, was exposed simultaneously. Additionally, aluminum

Figure 2A

⁴He PRODUCTION CROSS SECTION MEASUREMENT

RUN: AUG.4, 1983

INCHES
DO NOT SCALE

THIN ANGLE SECTION

NOTES:

1. ALL DIMENSIONS AND TOLERANCES ARE IN ~~INCHES~~ UNLESS OTHERWISE NOTED.
2. DIMENSIONING AND TOLERANCING PER ANSI Y14.5-~~1987~~ 2009.
3. POSITIONAL AND FORM TOLERANCES APPLY R.F.S. UNLESS OTHERWISE NOTED.
4. SURFACE TEXTURE PER ANSI IMC1. 2009.

Figure 2B

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LEGEND II

L7 = 7 LI METAL
L6 = 6 LI METAL
PB = PB HOUSING
RI = ROCKWELL INT. PACKAGE

SCALE : 2X

^4He PRODUCTION CROSS SECTION MEASUREMENT

ITEM		PART NO.		MATERIAL / DESCRIPTION		REV.		SPEC. NO.		STOCK NO.			
DR. R. LOUIE		2-17		CLASSIFICATION		MAJOR UNIT		2-17					
CHK. R. LOUIE		2/17/64				SUB ASSY.		2-17		2-17			
APPROVED R. LOUIE		2/17/64				DETAIL		2-17		2-17			
NO. REQ'D PER ASSY.		APPROVED R. LOUIE		DATE		LQ.		DRAWING NO.		AAA 2-17 2-17			
		SHOWN ON				COPY				SHEET 25			

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rings were positioned in grooves in the forward faces of F1, F2, F3, and F4 to permit independent fluence measurements and also spatial details of the fluence map. We included extra Nb foils at A2, A3, and A5 which were each cut up and counted to also provide an empirical fluence map. These results will not be discussed in the present note. Rather we will rely heavily on TART calculations to treat perturbations in a more holistic spirit.

Table II. Arrangement of Components in Sample Tube

Order:

A1	Au, Al, Nb, Ni, Zr
Spacer	1.0 cm nominal length
A2	Au, Al, Nb, Nb, Ni, Zr
F1	^6Li , (RI), ^7Li
A3	Au, Al, Nb, Nb
F2	^7Li , ^6Li , ^7Li
A4	Au, Al, Nb
Spacer	0.5 cm nominal length
A5	Au, Al, Nb, Nb, Ni, Zr
F3	^6Li , ^7Li , ^6Li
A6	Au, Al, Nb
F4	^7Li , ^6Li , Pb
A7	Au, Al, Nb
Spacer	0.5 cm nominal length
A8	Au, Al, Nb
F5	^7Li , Pb, ^7Li
A9	Au, Al, Nb
F6	^7Li , ^7Li , ^7Li
A10	Au, Al, Nb
Retainer	Thin walled SS tube

To avoid the possibility of recoil of α particles from adjacent material into the outer layers of the capsules, coupons of 1 mil Pb were inserted into the frame openings as the sample tube was loaded. Any stray α particles would have to penetrate at least 2 mils of Pb to lodge in a capsule wall.

The run was of 13 hr. duration, well suited to using the $^{27}\text{Al}(n,\alpha)^{24}\text{Na}$ reaction as a fluence monitor. The actual position of the sample tube with respect to the beam spot was determined with care. Prior to the run, a copper paddle positioned with respect to optical cross hairs was irradiated and an autoradiograph enabled us to locate the actual beam center. Since the beam spot was approximately 1.0 cm in diameter and its boundary was fuzzy and not quite circular, positioning was approximate. After the run, the Au and Nb foils at station A1 were autoradiographed. This revealed the actual beam spot center to be 2mm above and 2mm north of the sample tube axis.

TART Description

Optical measurements of the axial locations of the various Au foils within the sample tube were measured to an accuracy of < 10 mils. Using these as reference points a TART description was created incorporating modular (or average) descriptions of the capsules, frames, and foils - first a two-dimensional configuration in which the groups of three capsules were smeared together, and then a three-dimensional description with each capsule assigned to its own zone, a rectangular parallelepiped. The TART inputs for typical problems are listed in Appendix 1.

To minimize systematic error in the deviation of the experimental (n,α) cross section, the neutron source strength (S_{exp}) was inferred from activation foils immediately adjacent to the capsule in question. The cross-section is:

$$\sigma(n,\alpha)_{\text{exp}} = \frac{{}^4\text{He atoms/capsule}_{\text{exp}} \times (S_{\text{exp}})^{-1}}{{}^4\text{He atoms/capsule/source neutron}_{\text{TART}}} \times \sigma(n,\alpha)_{\text{TART}}$$

A correction for any difference in Li capsule mass from the modular description is included, and is generally less than a few percent. The modular masses are: 60.16 mg Li(95.6 mole % ^6Li) for a ^6Li capsule and 69.9 mg ^7Li (100% ^7Li) for a ^7Li capsule. For the former we have 0.9196g Pb while the Pb mass is 0.8852g for the latter.

Neutron Source Strength Determination

The sample holder was positioned with respect to the outer surface of the rotating target using a shim of 1.0 mm thickness. We recognize however that the effective gap may vary as the target rotates and as time progresses. Therefore the technique described earlier⁽¹⁾ (see Ref. 1, Fig. 5) has been applied. Briefly we fit the activation foil data as a function of axial position to TART predictions, varying the gap spacing to get the best fit. In the present instance, the best fit is achieved with a gap of 1.15 mm which translates to a spacing between the neutron source plane and frontal face of the leading Au foil of 3.252mm.

The TART geometry employed for source strength determination is illustrated in Fig. 3. This corresponds to the two-dimensional geometry. Inclusion of the rotating target mass is essential, as was seen from calculations in which the densities were reduced to insignificance. For example, the activity of the Nb foil immediately preceding capsule position 3 (see Table II, or Fig. 3) would be enhanced by 6% if all densities other than that of the foil were reduced by 10^3 . The rotating target accounts for ~ 70% of this effect. For ^4He production cross section derivation, the effect is compounded since the rotating target enhances ^4He production while reducing the threshold foil activities. We will return to this matter later.

The fluences inferred from the Al foils were based on the cross sections of Tagesen et al.⁽⁹⁾ For the Au foils, as well as for the Nb foils, the cross sections in TART reflected Nethaway's measurements^(12,13) corrected to the Tagesen set. Table III lists the source strength inferred from each foil. The notation of Table II is used.

Table III. Neutron Source Strength, RTNS-I Run of 8-4-83(x 10⁻¹⁶)

	<u>²⁷Al(n,α)</u>	<u>⁹³Nb(n,2n)</u>	<u>¹⁹⁷Au(n,2n)</u>	<u>PRC</u>		<u>$\bar{S}$</u>
A1	7.65	7.57	7.41	8.16		
A2	7.79	7.68	7.71		F1	7.74
A3	7.63	7.51	7.49		F2	7.67
A4	7.63	7.51	7.55			
A5	7.74	7.61	7.61		F3	7.73
A6	7.56	7.50	7.60		F4	7.74
A7	7.80	7.58	7.52			
A8	7.88	7.71	7.65		F5	7.85
A [~]	7.87	7.62	7.61		F6	7.86
A10	7.90	7.73	7.62			
Av:	7.76 ± .11	7.60 ± .09	7.58 ± .09	8.16 ± .41		7.77 ± .08

Also listed is a source strength inferred from the two proton recoil counters⁽²⁾ which view the rotating target from the rear. If we assign, in approximate accordance with our judgment of the uncertainty appropriate to each method, a unit weight to the source strength inferred from ²⁷Al(n,α)²⁴Na measurements and one-quarter weight to each of

¹²D. R. Nethaway, Nuc. Phys. A190 (1972) 635-644

¹³D. R. Nethaway, J. Inorg. Nucl. Chem. 40 (1978) 1285-1286
(⁹³Nb(n,2n) ^{92m}Nb)

Figure 3

TART Two-Dimensional Geometry Aug. 4, 1983 RTNS-I Run

CAPSL02-8/22/83

the other three values, we generate the final column of Table III. These values of S are used for inferring cross section values. It is reassuring to note that the standard deviation among the six values is only one percent.

^4He Measurements

All of the measurements of ^4He in the capsules were made at Rockwell International Energy Systems Gp., Canoga Park. The sample tube housed five ^6Li capsules, ten ^7Li capsules, two Pb tubes, and one Rockwell-International package. The peak ^4He content recorded for the ^6Li capsule closest to the source was 6.70×10^{12} atoms. The corresponding number for the ^7Li capsule was 3.73×10^{12} atoms. We also exposed three capsules, two of them ^6Li and one ^7Li , on axis and 1.0 m from the source. All were read out along with several unexposed capsules to establish ^4He background. Accuracy of readings well above background was generally $\pm 2\%$.

The background for the ^6Li capsules, based on ten readings, was $(9.2 \pm 4.6) \times 10^{10}$ atoms of ^4He . The distribution was not gaussian, with the maximum value at 1.7×10^{11} atoms. Fortunately the readings of the capsules housed in the capsule tube were substantially above background.

For the ^7Li capsule background, a value based on four readings was $(8 \pm 8) \times 10^{10}$. Half were very low and half $\sim 1.7 \times 10^{10}$ atoms. The $^7\text{Li}(n,\alpha)$ cross section will be seen as a result to be of poorer quality than its ^6Li counterpart.

Room background contributions can be inferred approximately from the capsule positioned at 1.0m. For the ^6Li capsules, two readings,

corrected for a slight direct contribution for the source, gives 7.9×10^{10} atoms, which is lower than the average background cited above. We also ran TART MC calculations in which a concrete wall 1.0m thick was described ($R_{\text{Min}} = 5.0\text{m}$). No ^4He enhancement was observed for the closer capsules while the farthest (i.e., F6) had their ^4He production enhanced by $\sim 2\%$, which was the TART statistical uncertainty. The calculations showed no alteration of the $^7\text{Li}(n, \alpha)$ process. We will therefore consider room return to be negligible.

Cross Section Determination: $^6\text{Li}(n, \alpha)$ and $^7\text{Li}(n, \alpha)$

The procedure for cross section determination depends heavily on application of the TART code. The expression for $\sigma(n, \alpha)_{\text{exp}}$ was given earlier (p. 14). If the calculated value of:

$$J = (^4\text{He atoms/capsule/source neutron})$$

is equal to the experimental counterpart, the experimental cross section is equated to the TART value. The experimental cross section is assumed to track linearly with ^4He production when $J_{\text{exp}} \neq J_{\text{TART}}$. At $E_N = 15.0$ MeV, the TART(ENDL) values for $\sigma(n, \alpha)$ are:

$$^6\text{Li}: \sigma(n, \alpha) = 0.520\text{b}$$

$$^7\text{Li}: \sigma(n, \alpha) = 0.3007\text{b}$$

The contribution of ^4He from the Pb housing for each capsule is taken to be zero. The ^4He production in the Pb shell at position F1 (-the forward most position) was measured to be 1.8×10^{10} atoms of ^4He . If background is assumed to be zero, we infer a ^4He production cross section of 4.3 mb. On the other hand, Kneff measured this cross

section at RTNS II to be $0.62 \pm .05 \text{ mb}^{(14)}$ which would imply a Pb contribution of 2.6×10^9 atoms of ^4He . Recalling our background values, the Pb contribution will be neglected.

^6Li

The measured ^4He content of the five ^6Li capsules housed in the sample tube, prior to background subtraction of 9.2×10^{10} atoms of ^4He , is listed in Table IV. The three-dimensional TART description was employed to generate $\sigma(n, \alpha)$ by the procedure outlined above.

Table IV. ^4He Readings of ^6Li Capsules, and Inferred Cross Sections

<u>Frame</u>	<u>Capsule No.</u>	<u>$^4\text{He} \times 10^{-10}$ (atoms)</u>	<u>$\sigma(n, \alpha)$ (b)</u>
1	6 - 101	670	.513
2	6 - 102	446.1	.518
3	6 - 99	214.5	.498
3	6 - 100	221.1	.521
4	6 - 98	168.9	.509

If we attribute a 2% statistical uncertainty to the ^4He readings and a background uncertainty of $\pm 4.6 \times 10^{10}$ atoms ^4He , we find a grand average of:

$$^6\text{Li}: \sigma(n, \alpha) = 0.512 \pm .007\text{b} \quad (E_N = 15.0 \text{ MeV})$$

The uncertainty does not include the contribution from the neutron source strength or model approximations.

¹⁴D. W. Kneff and H. Farrar IV, Rockwell International Progress Report (April-June 1982) ("Helium Generation in Fusion Reactor Material")

The above value is in excellent agreement with the TART (ENDL) value of 0.520b. Our first experimental attempt⁽¹⁾ which employed R-I capsules in much more compact geometry gave a ^4He production cross section of .523b which agrees, within experimental uncertainty, with the present value of .512b.

Direct comparison of TART predictions to observation handicaps us in the error assessment process, since we "lump" so much together. Ideally a cross section measurement should not involve large correction factors. We can assess such factors via TART calculations. In the present instance one question to ask is: how much is the ^4He production modified by the masses of relevant structures, such as the rotating target, Pb alignment frames, and activation foils? TART calculations show that if all densities are reduced by 10^3 , the ^4He production per capsule is measurably altered, the effect increasing as distance from the source increases. An average ^4He enhancement of $\sim 7\%$ by the structure masses is calculated. Conversely, the high energy fluence is calculated to decrease by $\sim 5\%$, leading to a $\sim 12\%$ effect on inferred cross section. Since we are confident of our modeling, we may anticipate a 2-3% uncertainty in the ^6Li cross section inference due to model oversights or deficiencies.

An additional TART calculation was run to assess the effect on (n, α) cross section determinations of an altered rotating target configuration. Since the beam axis does not coincide with the axis of symmetry of the target, the modeling of the target in two dimensional geometry crudely approximates actual conditions. To bound the effect first a target of 23 cm diameter was modeled to get the maximum possible effect. This was compared to a calculation in which the diameter was reduced to 12 cm, more representative of experimental geometry. The

$\sigma(n, \alpha)$ for both ${}^6\text{Li}$ and ${}^7\text{Li}$ at $E_N = 15.0$ MeV inferred is altered by less than 1%.

${}^7\text{Li}$

The quality of ${}^4\text{He}$ data for the ${}^7\text{Li}$ capsules was clearly inferior to that of the ${}^6\text{Li}$ capsules. For a given fluence the ${}^7\text{Li}$ capsules generated less ${}^4\text{He}$ while the uncertainty in the ${}^4\text{He}$ background was $\sim \pm 8 \times 10^{10}$ atoms of ${}^4\text{He}$. Table V lists the ${}^4\text{He}$ measured by mass spectrometry, before background subtraction of 8×10^{10} atoms of ${}^4\text{He}$, and the cross sections inferred from individual capsule readings.

Table V. ${}^4\text{He}$ Readings of ${}^7\text{Li}$ Capsules, and $\sigma(n, \alpha)$
Cross Sections

<u>Frame</u>	<u>Capsule No.</u>	<u>${}^4\text{He} \times 10^{-10}$ (atoms)</u>	<u>$\sigma(n, \alpha)$ (b)</u>
1	7-19	372.7	.333
2	7-24	272.6	.341
2	7-28	268.5	.349
3	7-30	123.5	.311
4	7-29	88.4	.282
5	7-33	68.8	.347
5	7-34	57.1	.277
6	7-25	50.9	.294
6	7-26	54.5	.318
6	7-27	67.4	.399

If we follow the procedure for determination of the average (n, α) cross section for ${}^7\text{Li}$ at $E_N = 15.0$ MeV, using a background uncertainty of $(\pm 8 \times 10^{10}$ atoms ${}^4\text{He})$ we find:

$${}^7\text{Li}: \sigma(n, \alpha) = 0.336 \pm 0.066 \text{ (} E_N = 15.0 \text{ MeV)}$$

The modeling uncertainty is somewhat less for the ${}^7\text{Li}$ case since the cross sections are characterized by thresholds, as are those of the activation foils. Accordingly we would suggest a 2% contribution from modeling uncertainty.

Three-dimensional calculations in addition to offsetting the source by an amount indicated by postrun autoradiography were warranted. Comparison of the 2D and 3D Tarts (Appendix 1 lists inputs) revealed a 7% difference at the closest capsule station for the bottom ${}^7\text{Li}$ capsule and a 4.5% difference for the corresponding ${}^7\text{Li}$ capsule at Station 2. For all other capsules the difference was less than 2%.

Conclusions

1. The neutron spectrum generated by 400 keV deuterons at RTNS-I in a fresh target was found to be accurately represented by the Seagrave calculations.
2. Using the accurate values of the ${}^{27}\text{Al}(n, \alpha){}^{24}\text{Na}$ and ${}^{90}\text{Zr}(n, 2n){}^{89}\text{Zr}$ cross sections, the measured ${}^{24}\text{Na}$ and ${}^{89}\text{Zr}$ activities implied:

$$\bar{E}_N (\theta = 0) = 14.95 \pm .04 \text{ MeV}$$

(The Seagrave value is 14.98 MeV.)

3. The variation in neutron yield vs E_d , the deuteron energy, suggested loadings of TiT_2 ($0+0.2$ mg/cm², the surface layer) and TiT ($0.2+1.2$ mg/cm², to the end of the track). The loading pattern alters $\bar{E}_N$ by only 0.05 MeV bringing $E_N(\theta = 0)$ to 15.03 MeV. The yield vs E_d curve using uniformly loaded $TiT_{1.5}$ and more up-to-date stopping cross sections closely resembles the curve of Seagrave based on TiT and stopping cross sections of mid-50's vintage.
4. Pulse-height distributions from a carefully positioned silicon surface barrier detector implied a value for $\bar{E}_N(\theta = 0^\circ)$ which remained constant as the target aged appreciably. A symmetric narrowing of the pulse height distribution suggests surface depletion accompanied by tritium depletion at the end of track. We would infer $E_N(\theta = 0^\circ) = 14.98$ MeV accordingly.
5. On August 4, 1983, a run was performed at RTNS-I to measure at $\bar{E}_N = 14.95$ MeV the 4He production cross sections for 6Li and 7Li . A low-mass assembly was used.
6. The neutron source strength was found to be $(7.77 \pm .08) \times 10^{15}$ neutrons. Heaviest reliance was placed on the $^{27}Al(n,\alpha)^{24}Na$ reaction, whose cross sections are known to high accuracy.
7. TART calculations were used extensively in the determination of the 6Li - and 7Li (n,α) cross sections. Three dimensional representation of the Li capsules was necessary for the closer capsules.
8. Room background was negligible, largely because the capsules were relatively close to the target.

9. The ^4He production cross sections are found to be:

$$^6\text{Li}: \sigma(n, \alpha) \approx 0.512 \pm 0.007\text{b}, \bar{E}_N = 14.95 \text{ MeV}$$

$$^7\text{Li}: \sigma(n, \alpha) \approx 0.336 \pm 0.006\text{b}, \bar{E}_N = 14.95 \text{ MeV}$$

They are to be compared to Howerton's (ENDL) values of 0.520b and 0.3007b, respectively.

Distribution

LANL

C. T. Alonso, L-18
J. D. Anderson, L-75
R. W. Bauer, L-405
N. A. Bonner, L-233
E. W. Burke, L-22
W. P. Chandler, L-16
A. A. Delucchi, L-234
J. M. Ferguson, L-35
M. A. Gardner/D. G. Gardner, L-234
W. Goishi, L-231
E. Goldberg, L-22
R. C. Haight, L-405
L. F. Hansen, L-405
R. J. Howerton, L-71
G. D. Kramer, L-71
J. M. LeBlanc, L-35
D. A. Leich, L-232
M. MacGregor, L-71
M. M. May, L-19
D. R. Nethaway, L-234
D. A. Nowak, L-13
D. W. Patterson, L-22
E. F. Plechaty/J. R. Kimlinger, L-71
C. H. Poppe, L-405
C. E. Rhoades, L-71
V. C. Rupert, L-22
H. D. Shay, L-23
C. F. Smith, L-232
W. J. Shotts, L-23
C. B. Tarter, L-71
P. C. Wheeler, L-23

D. W. Barr
J. M. Wallace

Appendix I, TART Inputs

name caps107 source offset
box 391 gene g. caps107,9-00-83

zplane 1 -600.
zplane 2 -500.
zplane 3 -15.
zplane 4 -14.
zplane 5 -.0500
zplane 6 .00
zplane 7 .00500
zplane 8 .01651
zplane 9 .02160
zplane 10 .04501
zplane 11 .05169
zplane 12 .00300
zplane 13 .00000
zplane 14 .10951
zplane 15 .1.10000
zplane 16 .1.0941
zplane 17 .1.13456
zplane 18 .1.13964
zplane 19 .1.25394
zplane 20 .1.64064
zplane 21 .1.54572
zplane 22 .1.65715
zplane 23 .1.56210
zplane 24 .1.56705
zplane 25 .1.60135
zplane 26 .1.90005
zplane 27 .1.97313
zplane 28 .1.98456
zplane 29 .1.98951
zplane 30 .2.51750
zplane 31 .2.52250
zplane 32 .2.53001
zplane 33 .2.53096
zplane 34 .2.54391
zplane 35 .2.56906
zplane 36 .2.57414
zplane 37 .2.60444
zplane 38 .2.97614
zplane 39 .2.98022
zplane 40 .2.99165
zplane 41 .2.99660
zplane 42 .3.11090
zplane 43 .3.39760
zplane 44 .3.40169
zplane 45 .3.41411
zplane 46 .3.41906
zplane 47 .3.94160
zplane 48 .3.94660
zplane 49 .3.95011
zplane 50 .3.96306
zplane 51 .4.07736
zplane 52 .4.36406
zplane 53 .4.36914
zplane 54 .4.30057
zplane 55 .3.95652
zplane 56 .4.45902
zplane 57 .4.70652
zplane 58 .4.79160

zplane 59 4.00303
zplane 60 4.80790
zplane 61 12.35714
zplane 62 600.
zplane 63 600.
cy1 64 0.3175
cy1 65 0.8324
cy1 66 0.7930
cy1 67 0.9425
cy1 68 1.1360
cy1 69 1.1455
cy1 70 1.2179
cy1 71 1.2700
cy1 72 1.2000
cy1 73 500.
cy1 74 600.
cy1 79 0.15075
cy1 80 0.6350
cono 75 30.45 -23.1704 0. 0.
cono 76 30.45 -23.2056 0. 0.
sphere 77 22.8600 -23.1704 0. 0.
sphere 78 23.0124 -23.1704 0. 0.
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jb 2 6 -5 71 -67
jb 3 7 -5 71
jb 4 0 -7 71
jb 5 9 -8 70
jb 6 10 -9 71
jb 7 11 -10 71
jb 8 12 -11 70
jb 9 12 -11 71 -70
jb 10 13 -12 71
jb 11 14 -13 71
jb 12 15 -14 00
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jb 14 16 -15 66 -64
jb 15 16 -15 71 -66
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jb 17 18 -17 71
jb 18 20 -18 65
jb 19 19 -18 60 -65
jb 20 19 -18 71 -68
jb 21 20 -19 71 -65
jb 22 21 -20 71
jb 23 22 -21 71
jb 24 23 -22 00
jb 25 24 -23 64
jb 26 24 -23 66 -64
jb 27 24 -23 71 -66
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jb 31 26 -25 71 -65
jb 32 27 -26 71
jb 33 28 -27 71
jb 34 29 -28 00
jb 35 30 -29 70
jb 36 30 -29 71 -70
jb 37 31 -30 71
jb 38 32 -31 71

jb 39 33 -32 80
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jb 44 36 -35 71
jb 45 38 -36 65
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jb 47 37 -36 71 -68
jb 48 38 -37 71 -65
jb 49 39 -38 71
jb 50 40 -39 71
jb 51 41 -40 00
jb 52 43 -41 65
jb 53 42 -41 68 -65
jb 54 42 -41 71 -68
jb 55 43 -42 71 -65
jb 56 44 -43 71
jb 57 45 -44 71
jb 58 46 -45 00
jb 59 47 -46 70
jb 60 47 -46 71 -70
jb 61 48 -47 71
jb 62 49 -48 71
jb 63 50 -49 00
jb 64 52 -50 65
jb 65 51 -50 68 -65
jb 66 51 -50 71 -68
jb 67 52 -51 71 -65
jb 68 53 -52 71
jb 69 54 -53 71
jb 70 55 -54 00
jb 71 57 -55 65
jb 72 56 -55 68 -65
jb 73 56 -55 71 -68
jb 74 57 -56 71 -65
jb 75 58 -57 71
jb 76 59 -58 71
jb 77 60 -59 00
jb 78 61 -60 69
jb 79 61 -60 71 -69
jb 80 61 -57 72 -71
jb 81 4 -3 75
jb 82 77 -4 75 -3
jb 83 78 -7 76 -3
jb 84 5 -78 76 -3
jb 85 77 -3 76 -75
jb 86 5 -3 73 -76
jb 87 3 -2 73
jb 88 61 -5 73 -72
jb 89 62 -61 73
jb 90 63 -62 74
jb 91 62 -2 74 -73
jb 92 2 -1 74
jb 93 1
jb 94 -74
jb 95 -63
jb 96 9 -8 00 -79
jb 97 9 -8 71 -68
jb 98 15 -14 71 -80

jt 99 23 -22 71 -00
 jb 100 29 -28 71 -00
 jb 101 33 -32 71 -00
 jb 102 41 -40 71 -00
 jb 103 46 -45 71 -00
 jb 104 50 -49 71 -00
 jb 105 55 -54 71 -00
 jb 106 60 -59 71 -00
 matl 1 19.32 1.0 70197
 matl 2 2.7 1.0 13027
 matl 3 8.57 1.0 41093
 matl 4 8.90 1.0 20000
 matl 5 6.50 1.0 45000
 matl 6 3.7397 .2692 3006 .2956 3007 .0128 9019 &
 .0580 79197 .0251 78000 .3401 82000
 matl 7 3.31106 .22134 3006 .47550 3007 .30300 82000
 matl 8 3.3393 .44130 3006 .25266 3007 .30604 82000
 matl 9 3.0682 .29455 3006 .32341 3007 .30204 82000
 matl 10 3.0319 .62224 3007 .37776 82000
 matl 11 3.2542 .69509 3007 .38091 82000
 matl 12 11.3 1.0 02000
 matl 13 8.029 .0645 20000 .0903 1001 .0462 0016
 matl 14 7.900 1.0 26000
 matl 15 .001293 .2000 0016 .00000 7014
 matl 16 1.00000 .3333 0012 .6667 1001
 matl 17 2.30 .173 1001 .573 0016 .209 14000 &
 .022 13027 .004 26000 .019 20000
 eta .0001 90 91 92
 eta .5293 20 36 47 54 66 73
 matz 0 93 94 95
 matz 1 3 10 22 32 37 49 56 61 68 75
 matz 2 4 11 23 33 38 50 57 62 69 76 20 30 47 54 66 73
 matz 3 5 12 13 14 15 24 25 26 27 34 39 40 41 42 51 58 63 70 77
 r.tz 3 96 97 98 99 100 101 102 103 104 105 106
 matz 4 6 16 43
 matz 6 7 17 44
 matz 6 18
 matz 7 20
 matz 8 45
 matz 9 52
 matz 10 64
 matz 11 71
 matz 12 19 21 29 31 46 48 53 55 65 67 72 74
 matz 13 03
 matz 14 81 85 79
 matz 15 1 8 35 50 70 02 84 86 87 88 89
 matz 16 2 9 36 60 00
 matz 17 00 91 92
 sentl 1 1 2 10 3 200000 5 3 21 10 23 1 26 1 10 3.e-05
 sentl 12 2
 * scragrave source spectrum
 maec 1 .03199 1.0 .93969
 maech 1 1 1.63 14.3 17.94 14.5 30.19 14.7 22.84 14.9
 maech 1 5 14.60 15.1 12.72 15.3 0.0 15.56
 maec 2 .05091 .93969 .76604
 maech 2 1 1.45 14.2 14.49 14.4 30.43 14.6 23.19 14.8
 maech 2 5 13.77 15.0 9.42 15.2 7.25 15.4 0.0 15.6
 maec 3 .13034 .76604 5
 maech 3 5.41 14.2 40.15 14.4 30.09 14.6 17.75 14.8
 maech 3 5 5.79 15.0 0.0 15.1

maec 4 .16644 .5 .17366
 maech 4 1 57.97 14.106 42.83 14.396 0.0 14.596
 maec 5 .17365 .17365 -.17365
 maech 5 1 100. 14.085 0. 14.095
 maec 6 .15942 -.17365 -.5
 maech 6 1 100. 13.805 0. 13.015
 maec 7 .12743 -.5 -.76604
 maech 7 1 100. 13.555 0. 13.565
 maec 8 .00179 -.76604 -.93969
 maech 8 1 100. 13.375 0. 13.305
 maec 9 .02804 -.93969 -1.000
 maech 9 1 100. 13.265 0. 13.275
 source2 82 0.0 0.5 -.3252 0.0 0.2 0.2
 ltype 1 18 28 45 52 64 71 20 30 47 54
 ltype 1 3 10 22 32 37 49 56 61 68 75
 ltype 1 4 11 23 33 30 50 57 62 69 76
 ltype 1 5 12 13 14 15 24 25 26 27 34 39 40 41 42 51 58 63 70 77
 ltype 1 96 97 98 99 100 101 102 103 104 105 106
 ltype 1 6 16 43 7 17 44
 reacted 18
 reacted 20
 reacted 25
 reacted 52
 reacted 64
 reacted 71
 reacted 20
 reacted 30
 reacted 47
 reacted 54
 reacted 3
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 reacted 7
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 reacted 25
 reacted 44
 centim 1.0e+10
 end

Comments on TART CAPSL07 Input:

1.

Station	Capsule Zone	Material No.	No. of ^6Li Caps.	No. of ^7Li Caps	No. of Pb Tubes	No. of R.I. Caps.
1	18	6	1	1	1	6
2	28	7	1	2	0	0
3	45	8	2	1	0	0
4	52	9	1	1	1	0
5	64	10	0	2	1	0
6	71	11	0	3	0	0

2. The Au frontal face is at $Z = 0.00$ cm. (Au zone: 3)3. The neutron source is a disc, $R = 0.5$ cm, $Z = -.3252$ cm. (See source2)

4. Activation foils:

Material	Material No.
Au	1
Al	2
Nb	3
Ni	4
Zr	5

5. Seagrave source spectrum is given as histogram. e.g. MAEC 1 .03199 1.0 .93969 means that for $1 \geq \cos \theta \geq .93969$, the fraction emitted is .03199. Since the fractional solid angle is .030155, we see a slight anisotropy and forward peaking: 1.061. MAEEH notation: For angle bin 1, we have, for example, 1.63% of neutrons emitted between 14.3 and 14.5 MeV, 17.94% between 14.5 and 14.7 MeV, etc.

TART CAPSL07 Geometry
(Not to Scale)

- Zone Numbers Underlined
- Surfaces not Underlined

name caps3d2 3dim., source offset .2,.2cm
box xsl gene g. caps3d2,8-31-63

zplane 1 -60.5
zplane 2 -50.5
zplane 3 -15.
zplane 4 -14.
zplane 5 -.0550
zplane 6 .00
zplane 7 .00500
zplane 8 .01051
zplane 9 .02146
zplane 10 .04661
zplane 11 .08300
zplane 12 1.08300
zplane 13 1.08000
zplane 14 1.09951
zplane 15 1.10446
zplane 16 1.10941
zplane 17 1.13456
zplane 18 1.13964
zplane 19 1.14564
zplane 20 1.15172
zplane 21 1.15779
zplane 22 1.16386
zplane 23 1.16993
zplane 24 1.17600
zplane 25 1.18207
zplane 26 1.18814
zplane 27 1.19421
zplane 28 1.20028
zplane 29 1.20635
zplane 30 1.21242
zplane 31 1.21849
zplane 32 1.22456
zplane 33 1.23063
zplane 34 1.23670
zplane 35 1.24277
zplane 36 1.24884
zplane 37 1.25491
zplane 38 1.26098
zplane 39 1.26705
zplane 40 1.27312
zplane 41 1.27919
zplane 42 1.28526
zplane 43 1.29133
zplane 44 1.29740
zplane 45 1.30347
zplane 46 1.30954
zplane 47 1.31561
zplane 48 1.32168
zplane 49 1.32775
zplane 50 1.33382
zplane 51 1.33989
zplane 52 1.34596
zplane 53 1.35203
zplane 54 1.35810
zplane 55 1.36417
zplane 56 1.37024
zplane 57 1.37631
zplane 58 1.38238
zplane 59 1.38845
zplane 60 1.39452
zplane 61 1.40059
zplane 62 1.40666
zplane 63 1.41273
zplane 64 1.41880
zplane 65 1.42487
zplane 66 1.43094
zplane 67 1.43701
zplane 68 1.44308
zplane 69 1.44915
zplane 70 1.45522
zplane 71 1.46129
zplane 72 1.46736
zplane 73 1.47343
zplane 74 1.47950
zplane 75 1.48557
zplane 76 1.49164
zplane 77 1.49771
zplane 78 1.50378
zplane 79 1.50985
zplane 80 1.51592
zplane 81 1.52199
zplane 82 1.52806
zplane 83 1.53413
zplane 84 1.54020
zplane 85 1.54627
zplane 86 1.55234
zplane 87 1.55841
zplane 88 1.56448
zplane 89 1.57055
zplane 90 1.57662
zplane 91 1.58269
zplane 92 1.58876
zplane 93 1.59483
zplane 94 1.60090
zplane 95 1.60697
zplane 96 1.61304
zplane 97 1.61911
zplane 98 1.62518
zplane 99 1.63125
zplane 100 1.63732

xplane 02 .19317
xplane 03 .19317
xplane 04 .19317
xplane 05 .19317
xplane 06 .19317
xplane 07 .19317
xplane 08 .19317
xplane 09 .19317
xplane 10 .19317
xplane 11 .19317
xplane 12 .19317
xplane 13 .19317
xplane 14 .19317
xplane 15 .19317
xplane 16 .19317
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xplane 62 .19317
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xplane 69 .19317
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xplane 72 .19317
xplane 73 .19317
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xplane 76 .19317
xplane 77 .19317
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xplane 84 .19317
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xplane 87 .19317
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xplane 89 .19317
xplane 90 .19317
xplane 91 .19317
xplane 92 .19317
xplane 93 .19317
xplane 94 .19317
xplane 95 .19317
xplane 96 .19317
xplane 97 .19317
xplane 98 .19317
xplane 99 .19317
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jb 41 34 -33 56 -64
jb 42 34 -33 71 -66
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jb 45 37 -35 81 -64 38 -36
jb 46 38 -35 81 -64 38 -36
jb 47 39 -35 81 -64 38 -36
jb 48 40 -35 81 -64 38 -36
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jb 92 84 -35 81 -64 38 -36
jb 93 85 -35 81 -64 38 -36
jb 94 86 -35 81 -64 38 -36
jb 95 87 -35 81 -64 38 -36
jb 96 88 -35 81 -64 38 -36
jb 97 89 -35 81 -64 38 -36
jb 98 90 -35 81 -64 38 -36
jb 99 91 -35 81 -64 38 -36
jb 100 92 -35 81 -64 38 -36

jb 101 25 -32 71 -80
 jb 102 41 -40 71 -80
 jb 103 46 -45 71 -80
 jb 104 50 -49 71 -80
 jb 105 55 -54 71 -80
 jb 106 60 -59 71 -80
 jb 107 81 -82 85 -86 20 -18
 jb 108 82 -83 85 -86 20 -18
 jb 109 83 -84 85 -86 20 -18
 jb 110 81 -82 85 -86 20 -24
 jb 111 82 -83 85 -86 26 -24
 jb 112 83 -84 85 -86 26 -24
 jb 113 91 -82 85 -86 38 -36
 jb 114 82 -83 85 -86 38 -36
 jb 115 83 -84 85 -86 30 -36
 jb 116 81 -82 85 -86 43 -41
 jb 117 82 -83 85 -86 43 -41
 jb 118 83 -84 85 -86 43 -41
 jb 119 81 -82 85 -86 52 -50
 jb 120 82 -83 85 -86 52 -50
 jb 121 83 -84 85 -86 52 -50
 jb 122 81 -82 85 -86 57 -55
 jb 123 82 -83 85 -86 57 -55
 jb 124 83 -84 85 -86 57 -55
 matl 1 19.32 1.0 79197
 matl 2 2.7 1.0 13027
 matl 3 8.57 1.0 41093
 matl 4 8.90 1.0 28800
 matl 5 6.50 1.0 40880
 matl 6 3.3676 .6600 3006 .0311 3007 .3089 82000
 matl 7 3.2820 .6999 3007 .3001 82000
 matl 8 2.5301 1.0 82000
 matl 9 4.5688 .0277 3006 .0308 3007 .0585 9019 .2829 79197 &
 .1224 70000 .4777 82000
 matl 12 1.3 1.0 02000
 matl 13 8.029 .0645 20000 .0903 1001 .0452 8016
 matl 14 7.900 1.0 26000
 matl 15 .001293 .2000 0016 .0000 7014
 matl 16 1.0000 .3333 6012 .6667 1001
 matl 17 2.30 .173 1001 .573 8016 .209 14000 &
 .022 13027 .004 26000 .019 20000
 eta .0001 90 91 92
 matz 0 93 94 95
 matz 1 3 10 22 32 37 49 65 61 60 75
 matz 2 4 11 23 33 38 50 57 62 69 76
 matz 3 5 12 13 14 15 24 25 26 27 34 39 40 41 42 51 58 63 70 77
 matz 3 95 97 98 99 100 101 102 103 104 105 106
 matz 4 5 16 43
 matz 5 7 17 44
 matz 6 107 111 113 115 117
 matz 7 109 110 112 114 116 119 121 122 123 124
 matz 8 119 120
 matz 9 108
 matz 12 18 19 20 21 28 29 30 31 45 46 47 48
 matz 12 52 53 54 55 64 65 66 67 71 72 73 74
 matz 13 83
 matz 14 81 85 79
 matz 15 1 8 35 59 78 82 84 86 87 39 89
 matz 16 2 8 36 60 83
 matz 17 80 91 92

sentl 1 1 2 10 3 200000 5 3 21 10 23 ! 26 1 10 3.0-03
 sentl 12 3
 * seagrave source spectrum
 maoc 1 .03199 1.0 .93969
 maoc 1 1 1.63 14.3 17.94 14.5 30.19 14.7 22.84 14.9
 maoc 1 5 14.60 15.1 12.72 15.3 0.0 15.56
 maoc 2 .09091 .93969 .76604
 maoc 2 1 1.45 14.2 14.49 14.4 30.43 14.6 23.19 14.6
 maoc 2 5 13.77 15.0 9.42 15.2 7.25 15.4 0.0 15.6
 maoc 3 .13034 .76604 .5
 maoc 3 1 5.41 14.2 40.15 14.4 30.89 14.6 17.76 14.0
 maoc 3 5 5.79 15.0 0.0 15.1
 maoc 4 .16644 .5 .17365
 maoc 4 1 57.97 14.196 42.03 14.396 0.0 14.595
 maoc 5 .17365 .17365 -.17365
 maoc 5 1 100. 14.085 0. 14.095
 maoc 6 .15942 -.17365 -.5
 maoc 6 1 100. 13.809 0. 13.815
 maoc 7 .12743 -.5 -.76604
 maoc 7 1 100. 13.555 0. 13.565
 maoc 8 .08179 -.76604 -.93969
 maoc 8 1 100. 13.375 0. 13.385
 maoc 9 .02804 -.93969 -.1.000
 maoc 9 1 100. 13.265 0. 13.275
 source2 82 0.0 0.5 -.3252 0.0 0.2 0.2
 ttype 1 107 111 113 115 117 109 110 112 114 116 119 121 122
 ttype 1 118 120 100 124 123
 ttype 1 3 10 22 32 37 49 56 61 60 75
 ttype 1 4 11 23 33 38 50 57 62 69 76
 ttype 1 5 12 13 14 15 24 25 26 27 34 39 40 41 42 51 55 63
 ttype 1 96 97 98 99 100 101 102 103 104 105 106 70 77
 ttype 1 6 16 42 7 17 44
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 centim 1.70+10
 and

Comments on TART CAPS3D2 Input:

1. The two dimensional geometry of CAPSL07 is changed to a structure in which individual capsules are allocated their own zones.

Frontal Views

Region 1, containing the capsules is altered to $1' + 2' + 3'$ while the Pb regions $2 + 3 + 4$ are converted to $4' + 5' + 6' + 7'$.

2. The material descriptions of individual capsule zones are:

Matl. 6: ^6Li capsule; zones 107, 111, 113, 115, 117
 Matl. 7: ^7Li capsule; zones 109, 110, 112, 114, 116, 119,
 121, 122, 123, 124
 Matl. 8: Pb tube; zones 118, 120
 Matl. 9: R-I package; zone 108