EVALUATION OF SSNTD STACKS EXPOSED ON THE ISS IN 2001 PRELIMINARY REPORT

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1) PURPOSE OF THE EXPERIMENT

The aim of the study was to investigate the contribution of secondary particles (mainly neutrons) in producing radiation damage to electronic devices and to astronaut-dose onboard of the International Space Station (ISS). Especially:

- To optimize solid state nuclear track detector (SSNTD) assemblies, have been used earlier for neutron dosimetry around nuclear facilities [1,2], for space dosimetry.
- To study the dose distribution at different locations of the ISS.
- To analyze etched track pictures of charge 'particle events' induced by high energy neutron interactions with Carbon and Oxygen atoms of SSNTDs exposed onboard of the ISS.
- To record by SSNTDs High Atomic Number and Energy (HZE) particle track onboard of the ISS for estimating their dose contribution.

2) METHODICAL TECHNIQUE AND DETECTORS

To study high LET radiation adequate detector system is required. As the result of experiments with energetic protons and fission fragments, a stack of Solid State Nuclear Track Detectors (SSNTDs) was developed which consists of three CR-39 sheets (TASTRAK, Bristol, UK, 0.6 % DOS plasticizer, 6 keV/μm detection threshold) of 1 mm thick having an area of 20 by 50 mm^2. The 1st and 2nd sheets were separated by a thin, high purity Ti foil (50 μm) of natural isotopic composition, the 2nd and 3rd sheets sandwiched a Lexan (General Electic, USA, foil of 350 μm thick). The assembly is shown in Fig. 1. The stack was wrapped in a thin Al foil (30 μm) and sealed hermetically in a polyethylene (PE) bag of 40 μm thick (not shown).

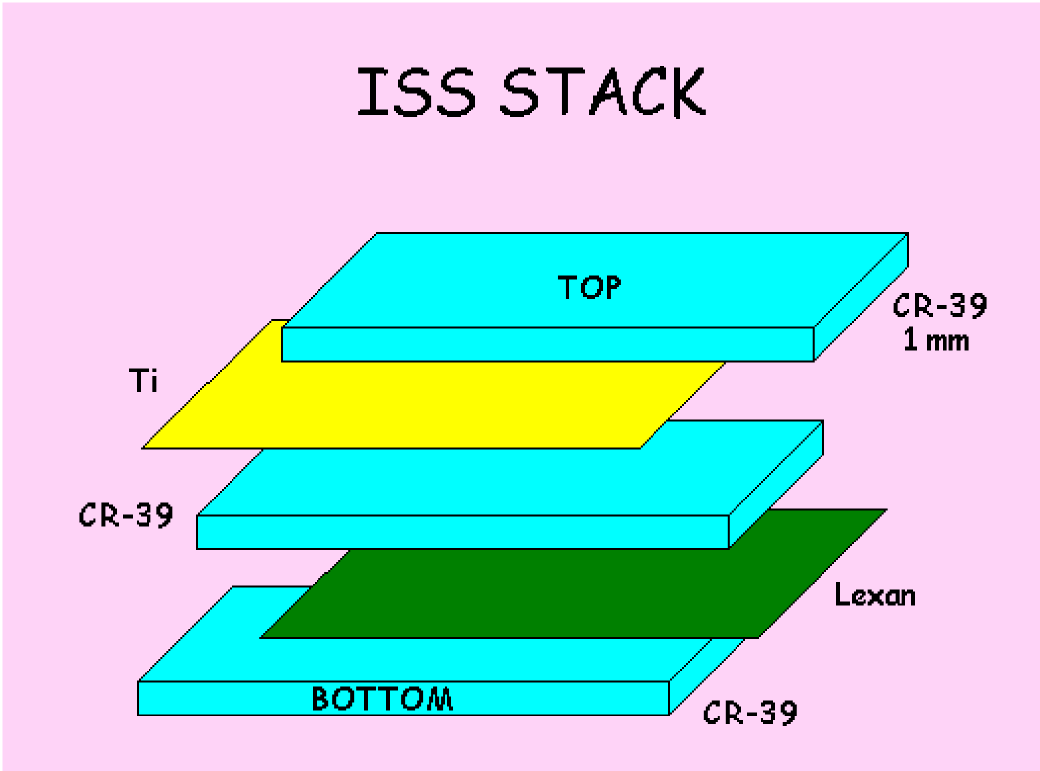


Fig. 1. Track detector assembly (stack) developed to determine the neutron dose on the ISS.

The neutron detection between ~100 keV and 4 MeV incident energy is based on the neutron elastic scattering on Hydrogen atoms within the detector material (in all CR-39 sheets) and detecting protons generated in converter materials as the Lexan detector itself (CR-39 sheet No. 3). The role of the Ti foil is twofold: degrades the energy of the high energy recoiled protons (coming if coming at all from CR-39 sheet No. 2) to fall into the detectable energy range (as above) and it works as a threshold detector utilizing the Ti(n,p)Sc reaction. The effective threshold is at ~2 MeV, extending the detectable neutron energy range up to ~20 MeV. See some info about the performance of Ti converters in [3].

All together 6 surfaces of the CR-39 detectors can be investigated by the image analyzer (VIRGINIA [4]) after etching. The neutron detection response of each surface was studied by the MCNP-4B, SRIM2000 and PROTON2000 (locally developed, not published) codes. The low energy proton response was tested by exposing the detectors to monoenergetic protons produced by a Van de Graaff generator. The background on each surface was measured before assembling the stacks, utilizing the pre-etching technique.

Seven identical stacks were manufactured and delivered to the ISS by the Progress 244 space craft on 24th Feb. 2001 and placed at different locations in the Russian segment 'Zvezda'. They were brought back to the Earth on the Sayouz TM-32 space craft on 31st Oct. 2001. The orbit apogee was from 400 to 420 km, the perigee was between 370 and 395 km. the orbit inclination was 51.8 °. The holder box of stacks flown is shown in Fig. 2. The total storage time before and after the exposure onboard was estimated to be 7 months.

Another 8 stacks, 6 different configurations, were exposed at the CERF high energy calibration field (Geneva, Swiss [5]) between 4 and 8 Oct. 2001, for calibration purposes.

Fig. 2

3) PRELIMINARY RESULTS

3.1. Based on calibrations at CERF the neutron doses were obtained at 6 different locations on the ISS. Summary.

The CR-39 detectors were evaluated in three steps: after 2 and 6 hours etching in 6N NaOH solution at 70 °C. The VIRGINIA analyzer allowed us to investigate the track parameters individually. Direct low energy proton and neutron induced proton tracks cannot be distinguished but the heavy C and O recoils, α and other light particles can be separated. All the tracks were stored in the computer in BMP image format in order to repeat the evaluation at any time. Statistical analysis was performed to obtain the dose: the number of circular tracks was counted on each detector sheet and the track densities obtained were compared. The dose values were deduced from each possible comparison to the calibration detectors and averaged for a given detector location. Since the CERF calibration spectra are somewhat different from the spectra at different positions inside the ISS, the overall uncertainty of the averaged dose rate has been estimated to be below ± 30 %.

It must be noted that the stack illustrated above is capable to determine the neutron ambient dose equivalent (H*) between ~200 keV and 20 MeV when etched for 6 h in 6 N NaOH at 70 °C (V_B=1.34 μm/h). The values given in Table 1 do not contain the neutron dose for higher energy neutrons above 20 MeV and that one below 200 keV. The contribution of neutrons, within the energy range mentioned, to the total neutron ambient dose equivalent can be estimated from published spectral information to be around 60 % [6].

The raw data obtained from Lexan detectors have not been analyzed yet.

Table 1. The neutron ambient dose equivalent rate at different position of the ISS measured between 24th 02 and 31st 10, 2001. The neutron energy range considered was between 200 keV and 20 MeV. The dose in this range can be 60 % of the total neutron dose. The initial background was subtracted but the background collected during the ~7 months storage time was not estimated and subtracted. The collected background dose rate of laboratory detectors stored in a refrigerator has been calculated for the duration of the flight and it is equivalent to ~ 1 μSv/d. No latent track fading was taken into consideration. The overall uncertainty for each location has been estimated to be below ± 30 %.

	Location in the ISS

H* rate μSv/d	#1, A11 panel 443	#2, A12 panel 240	#3, A13 panel 110	#4, A14 panel 457	#5, A15 panel 318	#6, A16 panel 110	#7, A16 panel 110 orthogonal	Average
	52	39	47	54	73	68	63	56.6 ±21%

3.2. Interactions with Carbon and Oxygen, detection of HZE particles

Both high energy neutrons may induce n,p and n,α reactions with Oxygen and Carbon atoms present in the CR-39 detector material (C_{12} H_{18} O_7). Large variety of energetic light particles may be formed during these events. The investigation of tracks from these interactions may result in a wider knowledge of the angular distribution of the secondary products, which may lead to more accurate reaction cross section values and may enable the estimation of neutron dose above 20 MeV. Approximately 4000 events were recorded so far on the 21 CR-39 sheets.

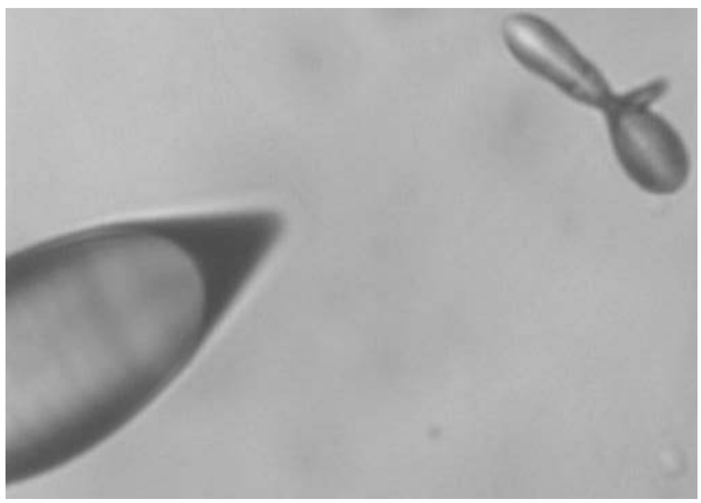
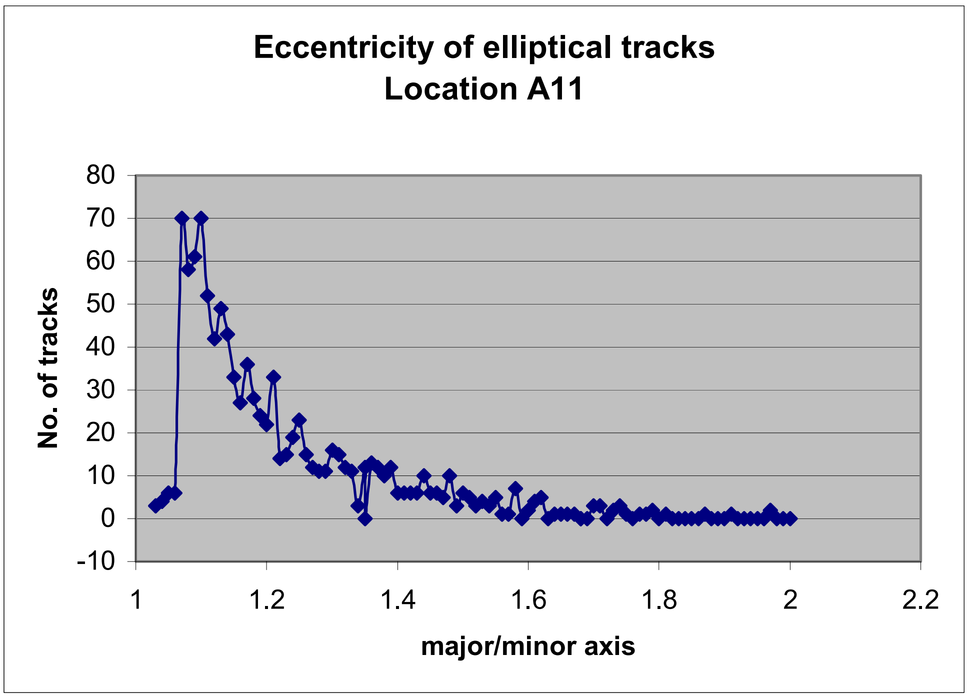


Fig. 3. A HZE track shown together with a charge 'particle event' in CR-39.

The evaluation of the neutron induced tracks formed inside the CR-39, as well as the investigation of the individual cosmic ray, HZE, tracks, detected by both the CR-39 and Lexan detectors, to determine the type and energy of particles, are still in progress (see Fig. 3). For evaluating the these events a geometrical model is being constructed, this will be followed by the preparation of a PC program to simulate the formation of such complex tracks in 3D.

3.3. Deduction of primary and secondary proton energy spectra from track parameter measurements

Beside the dose estimation, there is an attempt to assess the proton energy spectra utilizing the large amount of measured track parameters obtained from several subsequent etching steps (2, 6 and 12 h). The results may facilitate also the determination of the neutron spectra. For instance, (after 12 h etching) the measured eccentricity (Fig. 4), minor track diameter (Fig. 5) and the projected lengths (Fig. 6) of elliptical tracks allow to calculate the track length



distribution which can be correlated to the proton energy spectra. This work is in progress. Also these data may give information about the direction of the direct and neutron induced proton radiation.

Fig. 4

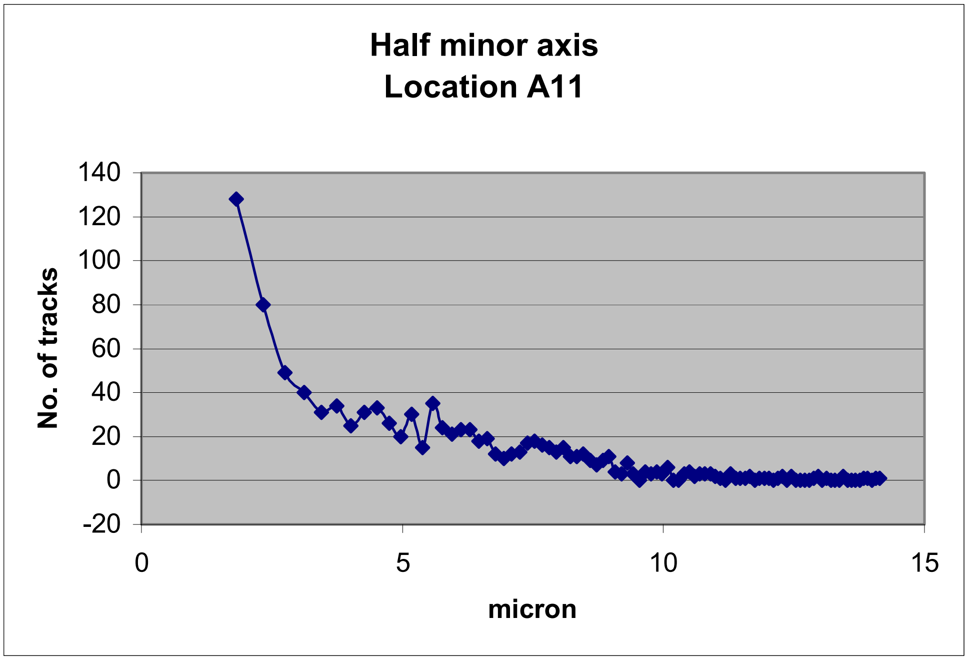

Half minor axis
Location A11
140
120
100
80
60
40
20
0
-20
No. of tracks
0
5
10
15
micron

Fig. 5

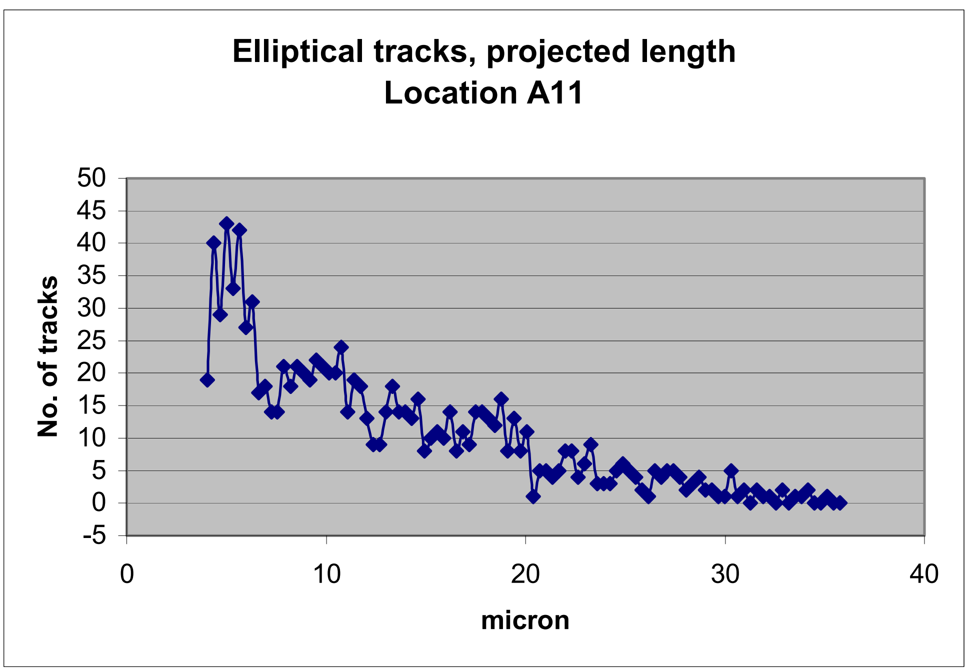

Elliptical tracks, projected length
Location A11
50
45
40
35
30
25
20
15
10
5
0
-5
No. of tracks
0
10
20
30
40
micron

Fig. 6

4) DISCUSSION

Although neither the measurements nor the evaluations have been completed yet, we can make some conclusions from the statistical evaluation of track parameter distributions.

- The evaluation of the eccentricity distribution of the elliptical tracks (see an example in Fig. 4) and the high percentage of circular tracks result in the conclusion that the direction of incident neutron radiation falls within a narrow angle (nearly perpendicular to the surface of detector or to the wall of the ISS where the stacks were fixed), so the angular distribution surely is not isotropic. This is valid for all the 6 locations investigated.
- Since the circular track area distribution is not significantly different for the 3 CR-39 sheets included in one stack, it can be said that the contribution from external protons is much less than that of the neutron induced protons (see Fig. 7), thus the role of external protons in the detectable energy range is negligible. Similar conclusion was presented in [7]. It must be noted, however, that the stacks were sealed in the metal box shown in Fig. 2, which, together with the wall, absorbs the low energy external protons.
- High energy neutron induced protons produce tracks with smaller track surface area or diameter because of the Bragg peek in LET function. There is a known correlation between the proton energy and the diameter beyond the Bragg peek. This may allow the reconstruction of the proton energy (LET) spectra. Since the number of tracks and also the area distributions under the Ti converter does not differ significantly from those of the other two detectors, we may say that the contribution of high energy neutrons, above 2 MeV to 20 MeV, is smaller than that of the neutrons below 2 MeV. This may mean that the neutron energy spectrum has a local minimum somewhere in this range or continuously decreases. Such a 'dip' was reported in [8] concluded from 4 STS experiments. The width of the minimum if exists or possible resonances are to be further investigated. There are not so many neutron spectrum calculations (predictions) and measurements inside the ISS available. One published theoretical calculation, based on a simplified model indicates a strong decrease in the total neutron flux above 10 MeV [6]. See the spectrum deduced from [6] in Fig. 8

expressed as Flux per unit log energy (lethargy), in cm^{-2} s^{-1} unit.

- Since the standard deviation of the averaged dose value is 21% and the overall uncertainty of each measurement is ± 30% (see Table 1), it can be said that the doses are not significantly different on the different places. Similar conclusion was obtained from the DOSMAP Experiment carried out in other segments of the ISS in 2001 [9]. The dose results shown in Table 1 can be, up to a given extent, compared to the results presented in [9-14] as shown in Table 2.

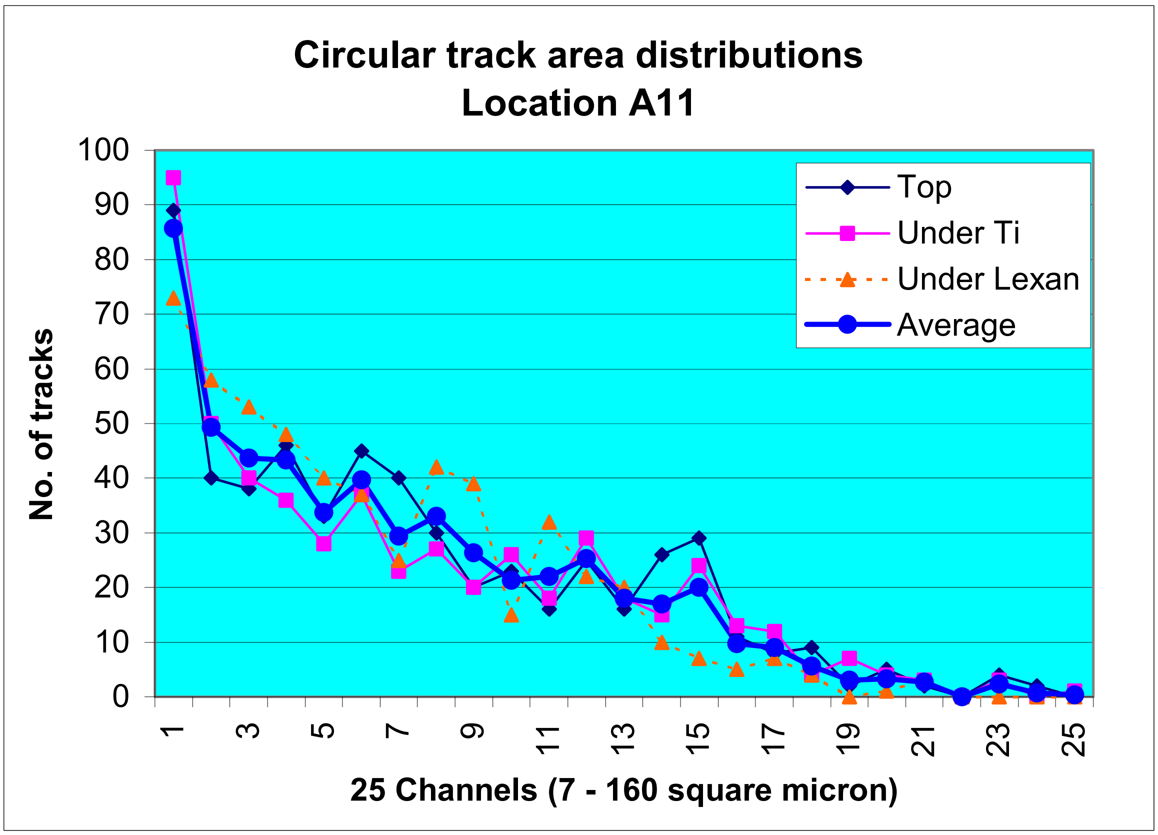


Fig. 7

Table 2. Neutron dose equivalent rates measured at approximately the same altitudes and inclinations using different combinations of etched track detectors (mainly CR-39). The energy or LET ranges considered may be different or not known, also the effective thickness and composition of shielding, as well as the way of calibration are different or not reported in the reference.

Location, author, Date, Reference	Dose equivalent rate * μSv/d
ISS, Russian segment 'Zvezda', Palfalvi, 2003, this paper	94 #
ISS, American Segment, E. Benton, 2002, [9]	173
STS-108, O'Sullivan, 2002, [10]	190
STS-108, Bartlett, 2002, [14]	130
STS-105, Bartlett, 2002, [14]	120
STS-91, Tawara, 2002, [13]	171
STS-91, Doke, 2002, [12]	183
STS-84, Tawara, 2002, [13]	141
STS-84, Doke, 2002, [12]	341
STS-84, Luszik-Bhadra, 1999, [7]	109, 125 **
STS-79, Doke, 2002, [12]	333
MIR, Doke, 2002, [12]	200
MIR, Spurny, 2002, [11]	85, 118 **
MIR, Luszik-Bhadra, 1999, [7]	66, 78, 235 **

Averaged, see Table 1.
* Either H*(10) or not defined
** Different locations

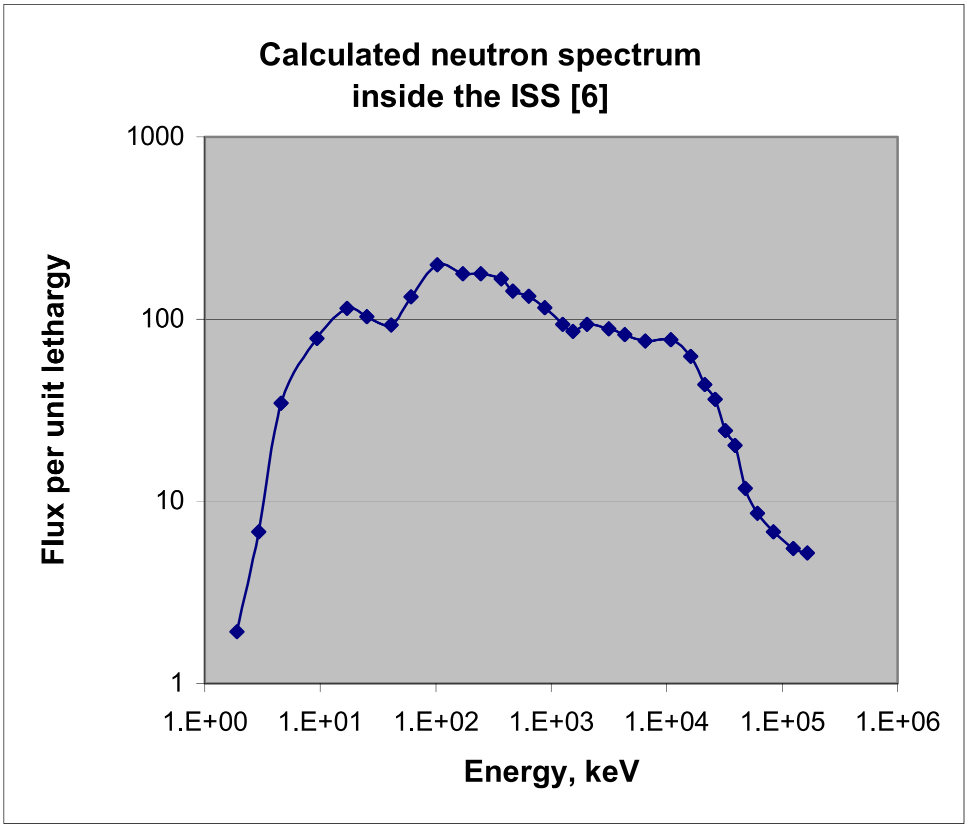


Fig. 8

5) ONGOING AND FUTURE WORKS

- Completion of measurements of the all the detectors extending the etching time up to 20 hours and internal comparison of the raw results (track parameter distributions) obtained by 3 different image analyzers of two co-operating groups.
- Re-calculation of the dose based on the improved and extended measurements, determination of LET spectra of charged particles detected.
- Repetition of the experiment onboard of the ISS (Russian segment) with slightly modified detector stacks.
- Elaboration of 3D modeling of high energy neutron interactions with C and O atoms, constitutive elements of CR-39 detectors.

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