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**APPENDIX C-2**

USF/Russian Dosimetry on STS-57

Two APDs were flown in the CPDS/TEPC locker on the Space Shuttle during the STS-57 mission. Due to placement, the shielding and radiation environment of the APDs were nearly the same and the dosimeters distributed in the two boxes can be considered equally exposed. The dosimeter types included plastic nuclear track detectors (PNTDs), TLDs, nuclear emulsions and thermal/resonance neutron detectors (TRNDs). The USF dosimeters included PNTDs, TLDs and TRNDs, while the Russian dosimeters included PNTDs, TLDs and nuclear emulsions. The contents of the two APDs (Serial Nos. 5716 and 5717) are shown in Figures 1-7.

The major purpose of this experiment was to conduct an international comparison of passive dosimetry methods in space. The results can also be compared to other dosimetry present on STS-57 and, since the shielding vectors of the containment locker are known, this will present an opportunity for comparisons with model calculations of radiation.

The STS-57 mission orbit had an altitude of 473 km and an inclination of 28.5°. The duration was 9.990 days. At this orbit the radiation was dominated by trapped protons and their secondary particles, with most of the dose being accumulated during Shuttle passages through the South Atlantic Anomaly (SAA).

The measured TLD absorbed doses are given in Table 1. Calibrations were made with a standard $^{137}$Cs source. Unfortunately, the Ground Control background TLDs became separated from the flight units during the return shipment but the background should have been a small correction. The average dose measured was 9.24 mGy. Other TLD doses measured in the Shuttle varied from 4.00 to 8.52 mGy, or somewhat less (Cash, 1993).

The low energy neutron fluences and dose equivalents, measured with the TRNDs, are given in Table 2. The measurements are averages from the front- and back-mounted TRNDs. The low energy neutrons contributed a very small fraction to total flight dose

equivalent, which was more than 1000 times less than that measured with TLDs. For STS-57, in the CPDS locker, this component of dose equivalent was negligible.

The LET spectrum measured with PNTDs is compared with that measured with the TEPC in Fig. 8. It is seen that the PNTD spectrum is higher at high LETs (above 80 keV $\mu m^{-1}$) and lower at low LETs (below 20 keV $\mu m^{-1}$). The higher high LET flux represents an improvement in PNTD response obtained with a new method of processing and readout. The spectrum represents a combination of the new (Method B) and standard techniques.

The reason for the greater PNTD flux at high LETs (compared with TEPC) is not clear, but one possibility is in the respective elemental compositions of CR-39 PNTDs and of the tissue-equivalent lining and gas of the TEPC sensitive volume. The CR-39 composition is $O_7C_{12}H_{18}$ while that of TEPC is close to $H_2O$. The particles forming high LET tracks on STS-57 were mainly short range (only a few $\mu m$) and were therefore secondaries created within the CR-39 by interactions between incident primary protons and target nuclei. A somewhat different secondary particle spectrum would be expected in TEPC. The TEPC had a higher partial density of H and correspondingly less of the heavier elements. When the energetic protons interact with the nuclei in the two detectors, there will be a higher probability for producing lower LET proton secondaries (elastically scattered H) in the TEPC and a higher probability for higher LET secondaries (from elastic and inelastic interactions with C and O) in the PNTDs.

In the LET region below 20 keV $\mu m^{-1}$ there is a possibility of loss of sensitivity due to the small track sizes and inhomogeneity of the detector surfaces. This may also account for a part of the decline of the PNTD spectrum below TEPC.

The integral flux, dose rate and dose equivalent rate for LET >5 keV $\mu m^{-1}$ are given in Table 3.

In order to determine the real dose and dose equivalent for STS-57, the TLD absorbed dose must be corrected for reduced sensitivity to high LET particles. The average efficiency for measurement of the absorbed dose in the LET spectrum can be found from

$$\epsilon = \sum_{5\ \mathrm{keV}/\mu\mathrm{m}}^{\mathrm{LET}_{max}} \epsilon(\mathrm{LET})\ D(\mathrm{LET})/D$$

where $\epsilon$(LET) is the efficiency curve as a function of LET (Fig. 9) and D(LET) is the differential dose spectrum. The equation gives $\epsilon = 0.60 \pm 0.05$ for STS-57. It should be noted that the LET spectrum in CR-39 plastic was not the same as that in TLD-700 because of a difference in the short range secondary particles generated in the two media. However, this will not have contributed substantial errors into the determinations of absorbed dose in this paper. The low LET component of absorbed dose is therefore

$$D_L = D_{TLD} - 0.60\ D_{PNTD}$$

and

$$D_H = D_{PNTD}$$
$$D_T = D_L + D_H$$

where $D_L$ and $D_H$ are the low- and high-LET absorbed doses, respectively, and $D_T$ is the total absorbed dose. The dose equivalent is given by

$$H_T = D_L + H_{PNTD}$$

and

$$\overline{QF} = H_T/D_T.$$

From the above

$D_{TLD} = 924 \pm 18$ mrad

$D_L = 855 \pm 20$ mrad LET <5 keV $\mu m^{-1}$

$D_H = 114 \pm 8$ mrad LET ≥5 keV $\mu m^{-1}$

$D_T = 969 \pm 20$ mrad

$H_T = 1910 \pm 80$ mrem

$QF = 1.97 \pm 0.11$

These quantities can be compared with the measurements

These quantities can be compared with the measurements reported by Badhwar et al. (1994). The TEPC measured totals of 1109 mrad and 2063 mrem for QF = 1.86. The TEPC absorbed dose and dose equivalent were therefore 14% and 78%, respectively, higher than our combined TLD/PNTD measurements, giving a slightly lower QF. The TEPC was placed in the same locker with the APDs, with very similar shielding. The difference may be due to factors such as measurement efficiencies of neutrons or other particles.

**TABLE 1.** TLD Absorbed Doses in STS-57 APDs

| APD Serial No. | Location | Absorbed Dose (mGy) | Dose Rate (mGy $d^{-1}$) |
|---|---|---|---|
| 5716 | Front | $9.29 \pm 0.28$ | 0.930 |
| | Back | $9.20 \pm 0.28$ | 0.921 |
| 5717 | Front | $9.36 \pm 0.28$ | 0.937 |
| | Back | $9.09 \pm 0.27$ | 0.910 |
| Average | | $9.24 \pm 0.12$ | 0.925 |

**TABLE 2.** Low Energy Neutron Fluence and Equivalent Dose from the STS-57 APD TRNDs

| Energy Range | Neutron Fluence ($cm^{-2}$) | Equivalent Dose mrem |
|---|---|---|
| <0.2 eV | $8.6 \pm 5.0 \times 10_3$ | $0.009 \pm 0.005$ |
| 0.2 eV--1 MeV | $1.5 \pm 0.7 \times 10_5$ | $0.74 \pm 0.35$ |

**TABLE 3.** Results of PNTD Measurements from the APD on STS-57

| Flux ($cm^{-2}s^{-1}sr^{-1}$) | Absorbed Dose Rate (mrad $d^{1}$) | Dose Equiv. Rate (mrem $d^{-1}$) | Total Dose Equiv. (mrem) |
|---|---|---|---|
| 3.22e-03 | 11.44 | 105.1 | 1050 |

## REFERENCES

Badhwar G.D., Atwell W., Benton E.V., Frank A.L., Keegan R.P., Dudkin V.E., Karpov O.N., Potapov Yu.V., Akapova A.B., Magradze N.V., Melkumyan L.V. and Rshtuni Sh.B. (1994). A study of the radiation environment on board the Space Shuttle flight STS-57. Rad. Meas. (in press).

Cash B. (1993). Mission STS-57 dosimetry report. NASA Lyndon B. Johnson Space Center Internal Report.

# Area Passive Dosimeter (APD) - Side View

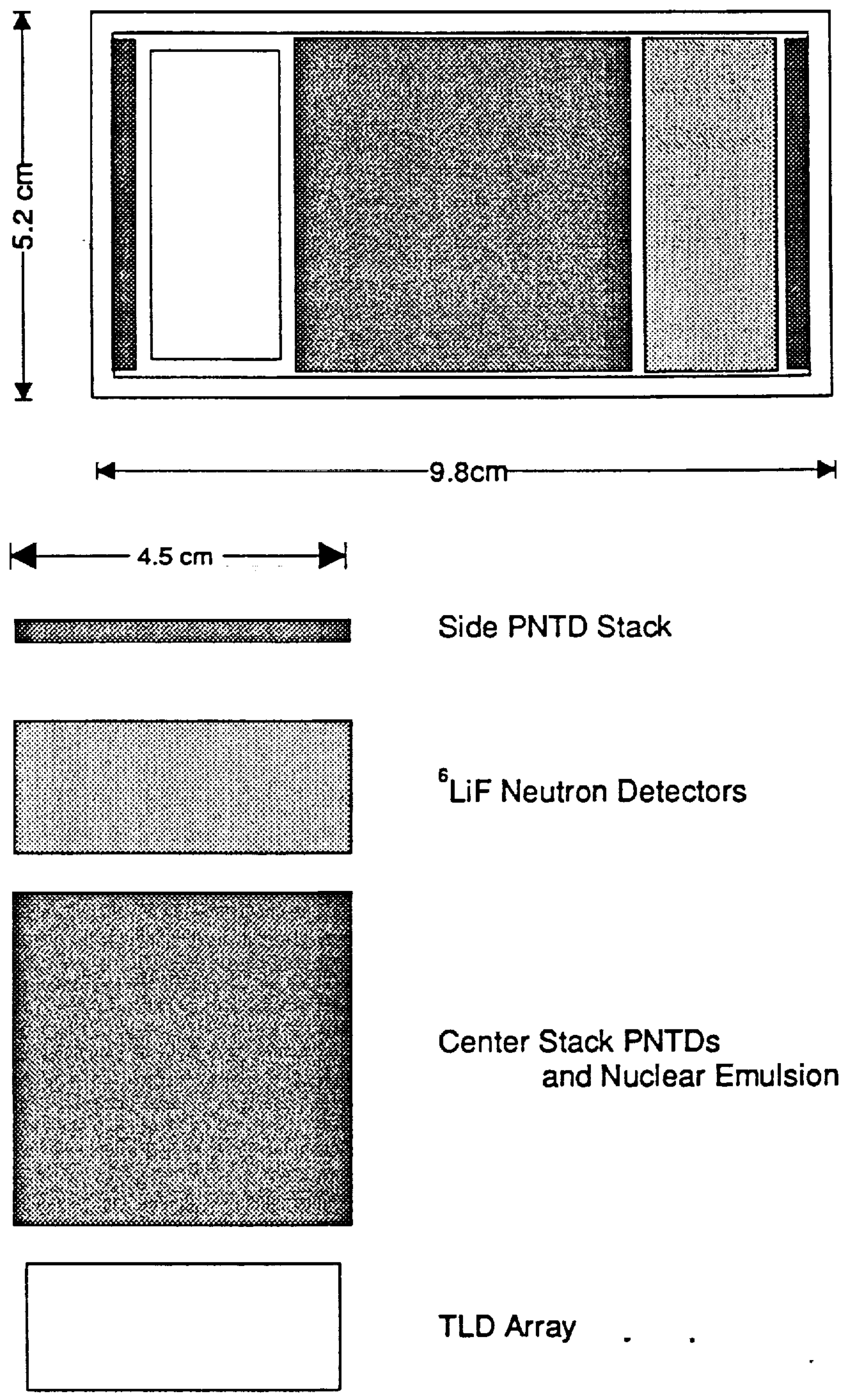


Figure 1: Side view of the APD box and its contents.

# Area Passive Dosimeter (APD) - Top View

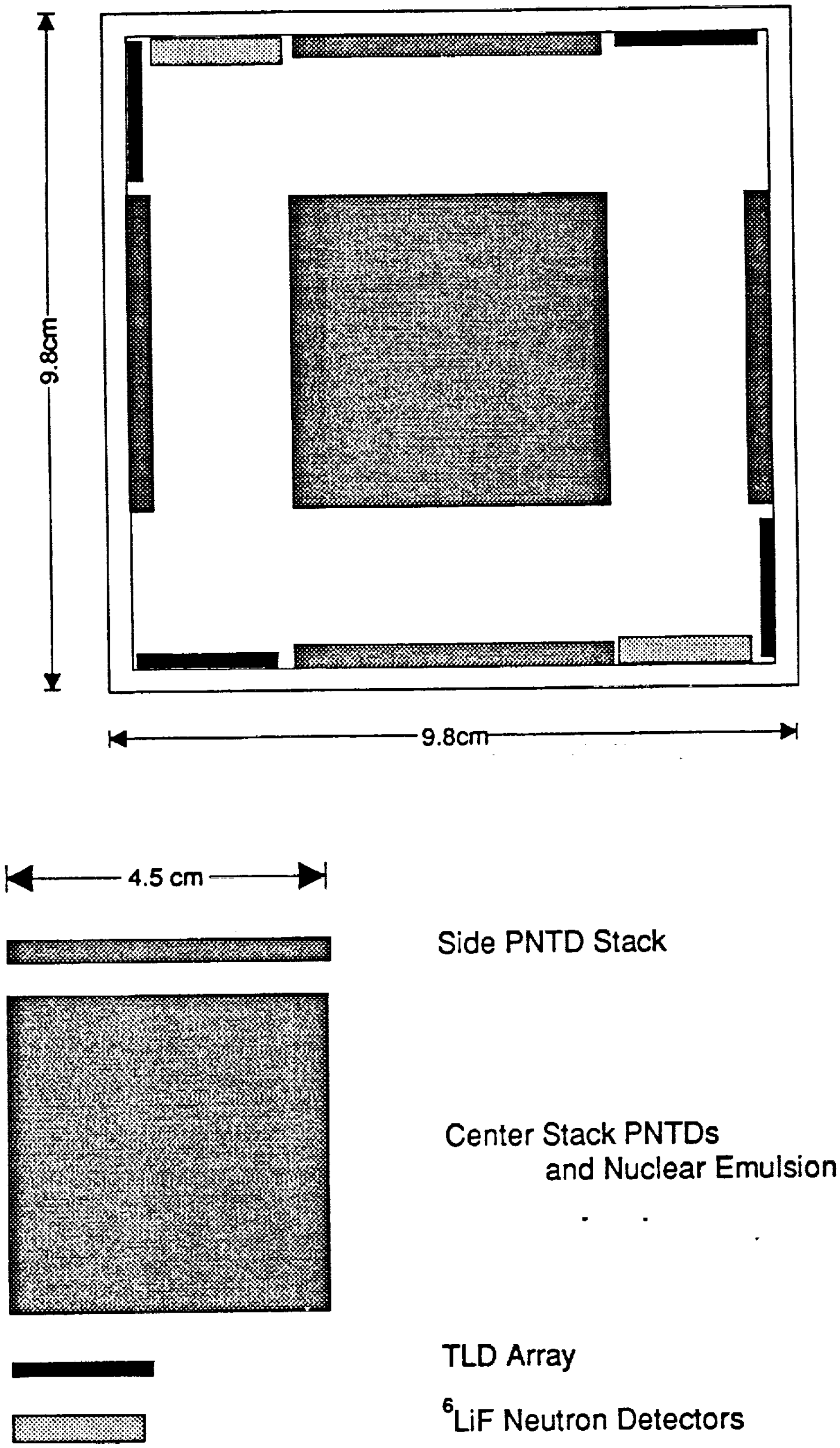


Figure 2: Top view of the APD box and its contents.

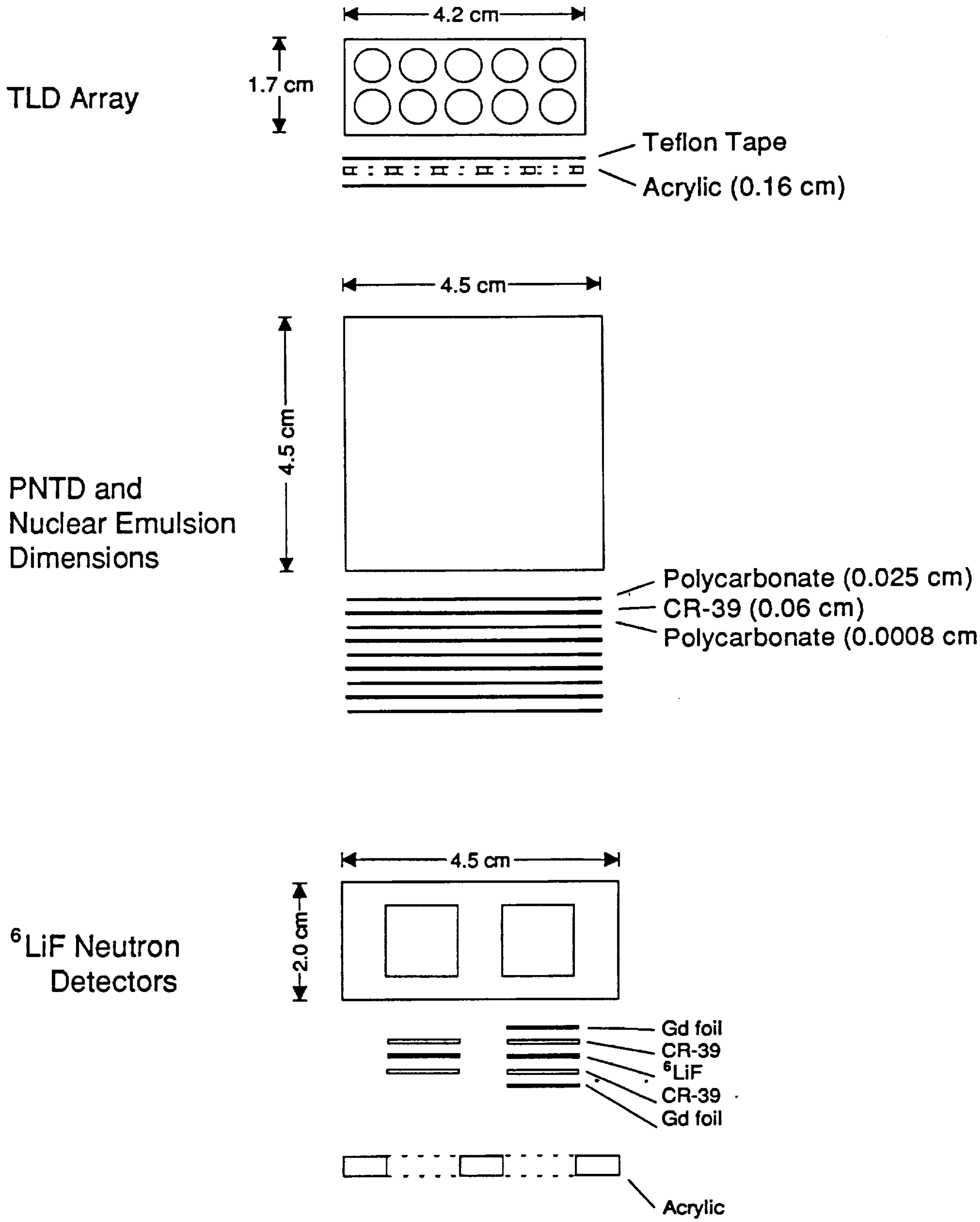


Figure 3: Dimensions of the TLD Array, PNTD center stack and TRND.

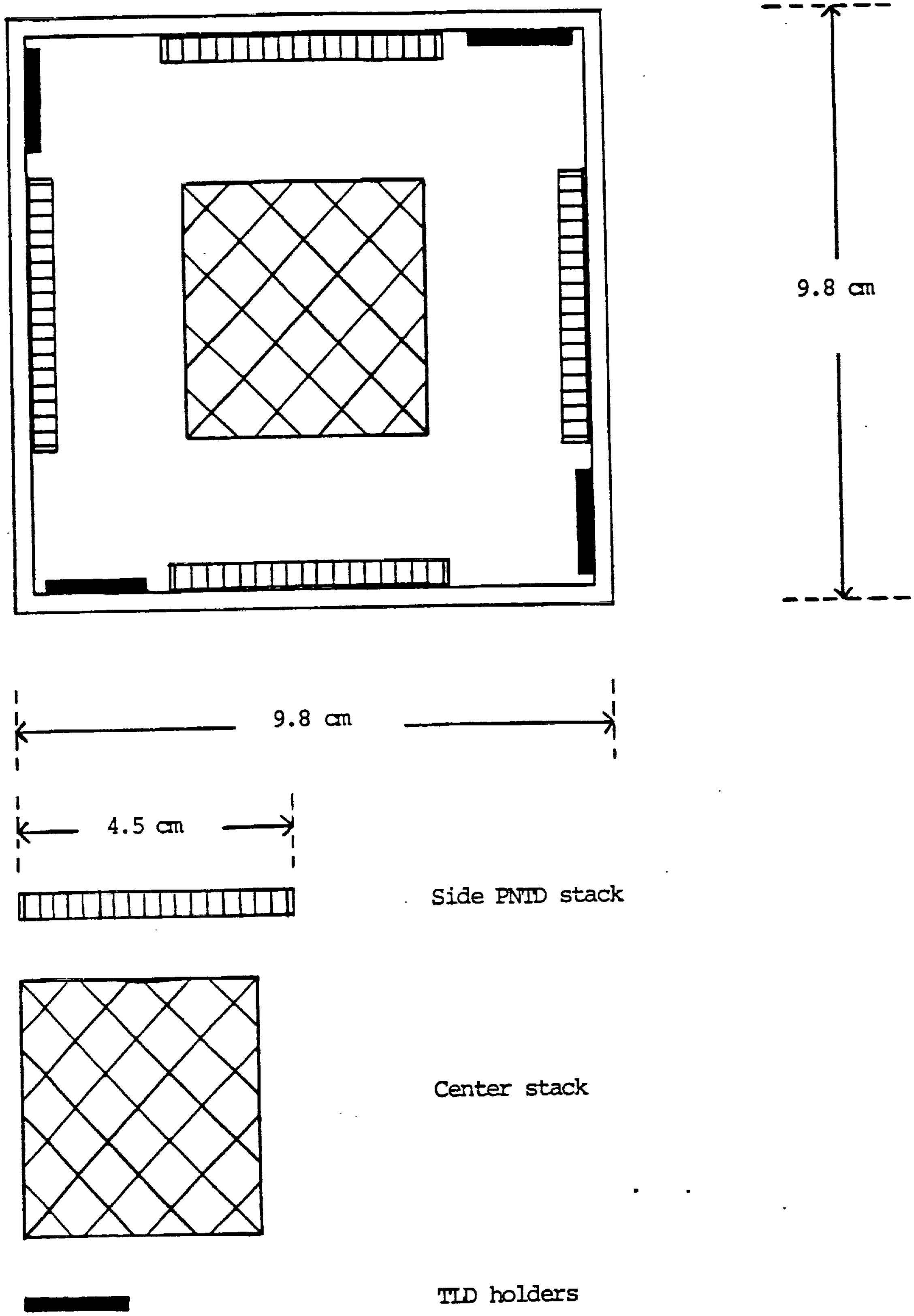


Fig. 4. Top view of APD #5717

PNTD Stack Dimensions

Outer PNTD Stack

Inner PNTD Stack

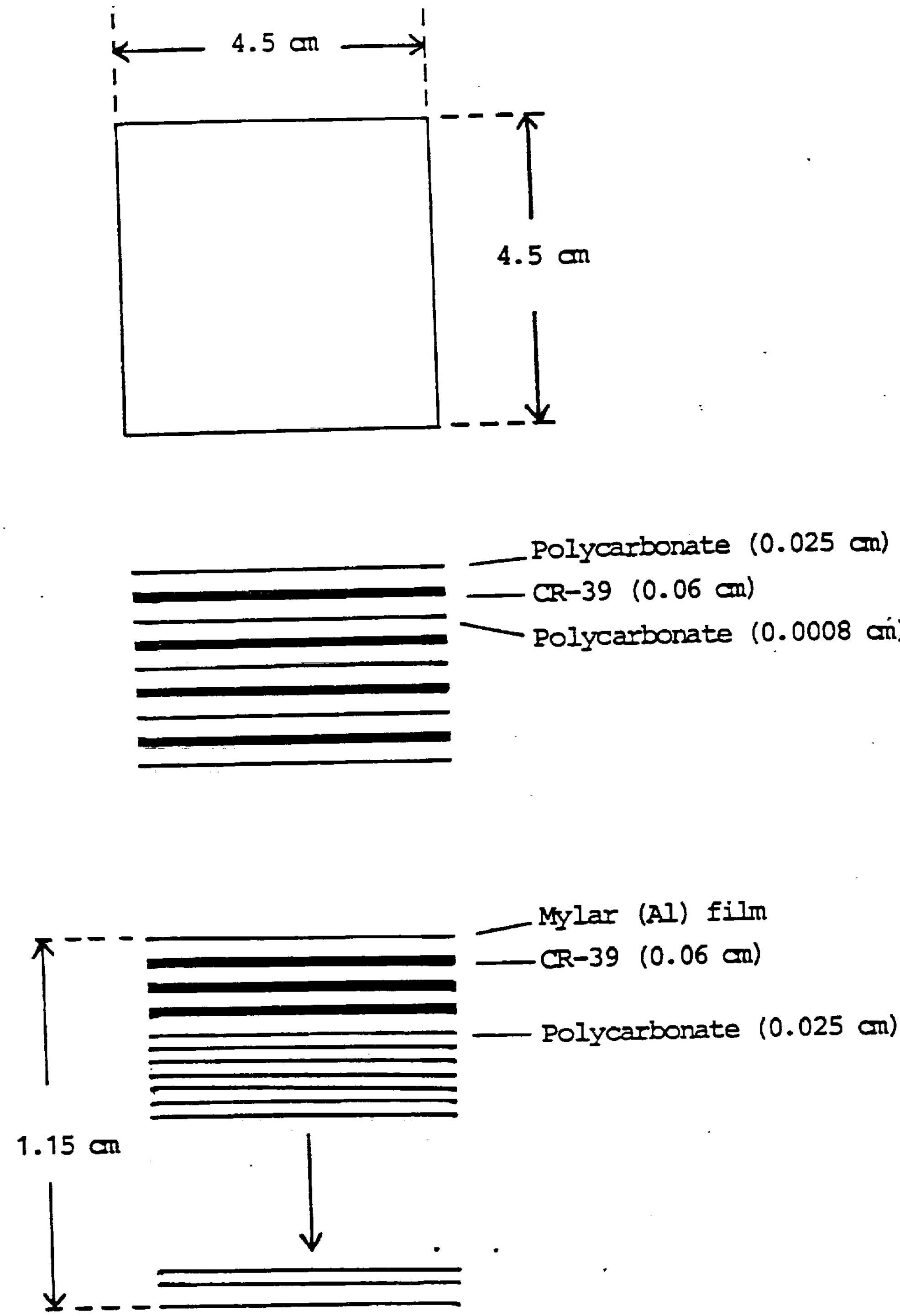


Fig. 5. Sketches of PNTD stack components and dimensions, APD #5717

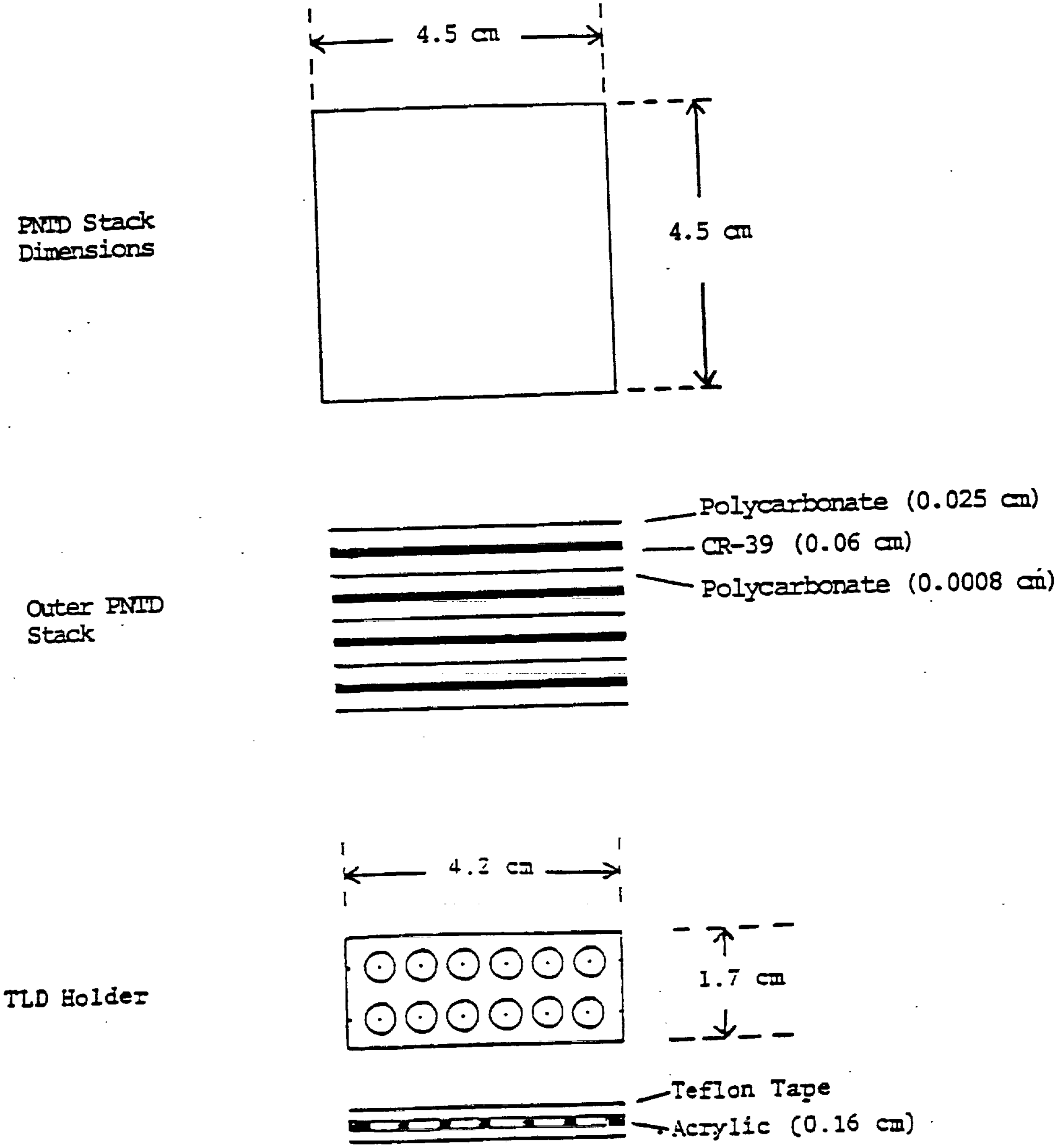


Fig. 6. Dimensions and components of the outer PNTD stacks and the TLD holder - PNTD #5717

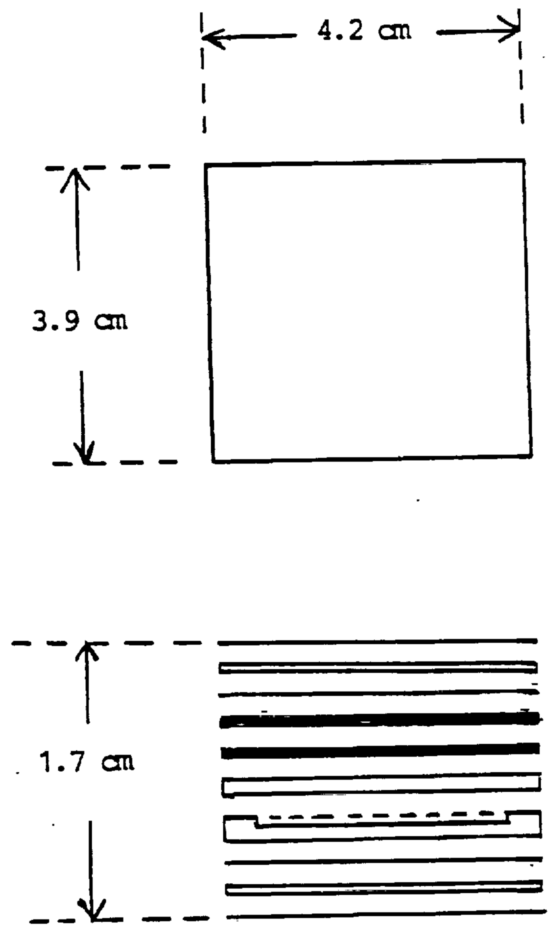


Fig. 7. Dimensions and components of the Center PNTD and TLD stacks - APD #5717

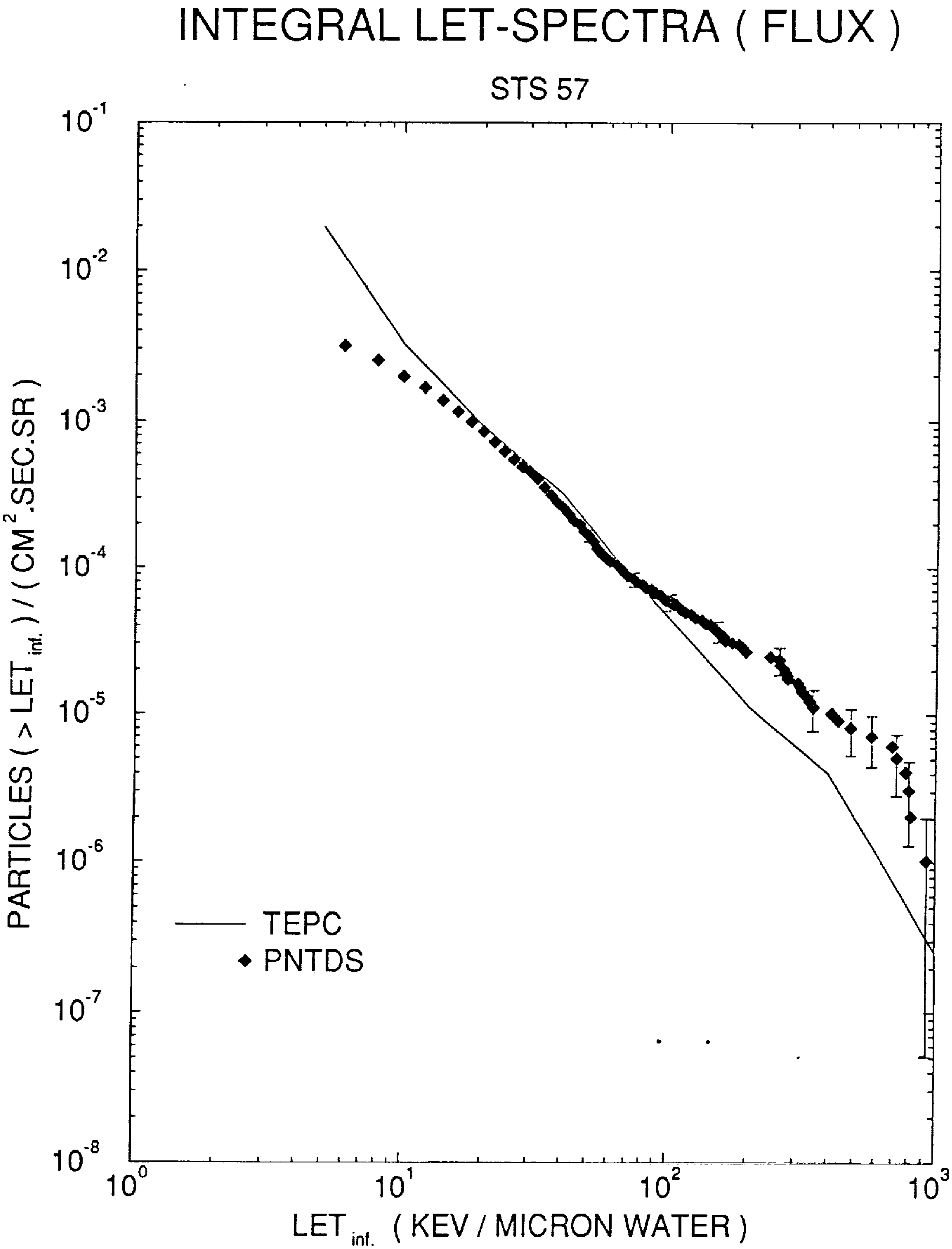


Fig. 8. Comparison of integral LET spectra measured by PNTDs and the TEPC microdosimeter on STS-57

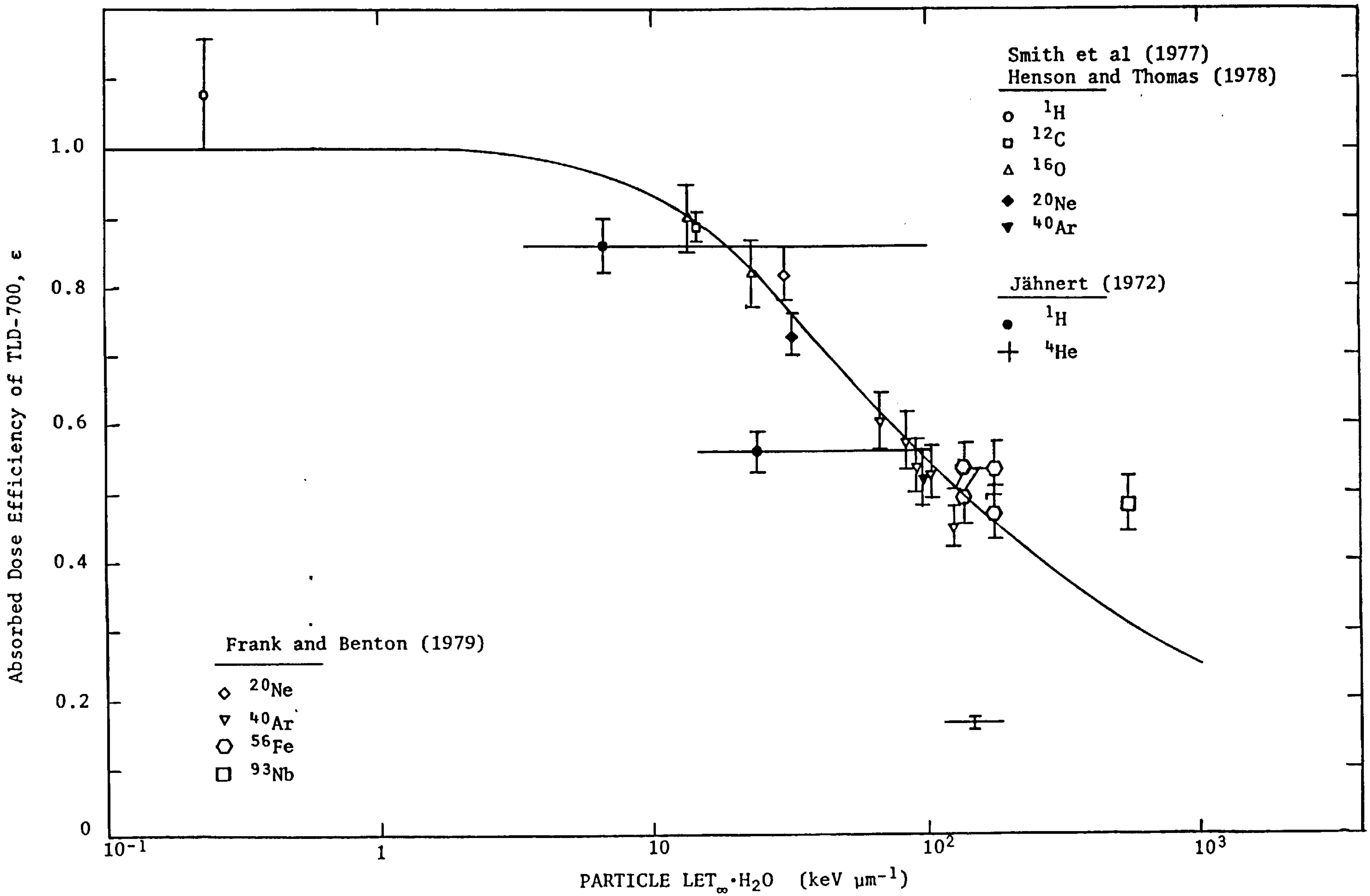


Fig. 9. Efficiency of measurement of absorbed dose as a function of LET for accelerated heavy ions on TLD-700 chips.