Environmental Radiation Measurements on the Mir Space Station: Program 1: Internal Experiment Program 2: External Experiment

1997 Progress Report

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Abstract: As part of the NASA/Mir Phase 1B Science Program, the ionizing radiation environment inside and outside the Russian Mirs Space Station was monitored using a combination of Thermoluminescent Detectors (TLD) and CR-39 Plastic Nuclear Track Detectors (PNTD). Radiation measurements inside the Mir station were carried out using six Area Passive Dosimeters (APD), four located inside the Mir Base Block and two located inside the Kvant 2 module, during the NASA-2/Mir-21, NASA-3/Mir-22 and NASA-4/Mir-23 missions. The radiation environment under low shielding was measured using an External Dosimeter Array (EDA) mounted on the outer surface of the Kvant 2 module. The external radiation environment and a location inside the Kvant 2 roughly corresponding to the location of the EDA were monitored for 130 days during the NASA-4/Mir-23 and NASA-5/Mir-24 missions. Dose rates measured by APD TLDs ranged from 271 to 407 μGy/d during the NASA-2/Mir-21 mission, from 265 to 378 μGy/d during the NASA-3/Mir-22 mission, and from 287 to 421 μGy/d during the NASA-4/Mir-23 mission. APD PNTDs have been analyzed and LET spectra have been generated for the five APDs exposed on the NASA-2/Mir-21 mission and for two APD PNTDs exposed on the NASA-3/Mir-22 mission. Dose equivalent rates on the NASA-2/Mir-21 mission ranged from 513 μSv/d in the Kvant 2 module to 710 μSv/d on the floor of the Base Block. Dose as a function of shielding depth in TLDs has been measured in the thin TLD stacks including in the EDA. EDA dose range from 72.5 Gy under 0.0146 g/cm^2 to 0.093 Gy under 3.25 g/cm^2 of shielding. Readout and analysis of the reaming PNTDs form the NASA-3/Mir-22 mission and PNTDs from the NASA-4/Mir-23 mission (including those from the EDA) is ongoing and will be completed during the final year of this experiment. Dose equivalent rates for the NASA-3/Mir-22 and NASA-4/Mir-23 APDs will then be determined and comparisons will be made with both model calculations and with results from similar measurements.

I. Introduction:

The NASA/Mir Science Program can be seen as marking the beginning of the permanent presence of American astronauts in space. Since March 1995, seven American astronauts have lived and worked aboard the Russian Mir Space Station for periods of up to nearly seven months. Later this year on-orbit assembly of the International Space Station (ISS) is scheduled to begin, marking yet another expansion in the permanent human presence in space. This increase in the number of personnel in low earth orbit (LEO) at any given time and the increased in the duration of each astronaut's stay in LEO will lead to an increase in the overall radiation exposure received by astronauts. Accurate prediction of accumulated radiation dose and dose equivalent to astronaut crews and the subsequent assessment of risk from long duration radiation exposure has therefore become of greater necessity if the long-term, stochastic effects of space radiation are to be minimized. Dose and dose equivalent prediction and risk assessment is based upon models of the radiation environment in LEO and on models of the transport of radiation through matter. These models are based in part on in-situ measurements of the radiation environment and additional measurements are needed to validate the accuracy of these models. In addition, an understanding of the different constituent components of the radiation environment in LEO is needed to base radiation modeling efforts on an analytical and not merely empirical foundation.

The determination of astronaut risk from environmental radiation on spacecraft in LEO requires accurate measurement of dose from the variety of ionizing particles present. The radiation quantity used for risk assessment is the radiation dose multiplied by the evaluated biological effectiveness of the radiation and is called the dose equivalent. The contribution to dose equivalent of an ionizing particle is a product of its energy deposition in tissue, called the linear energy transfer (LET), and the LET dependent Quality Factor (QF). QF is an evaluated fit to the radiobiological efficiency (RBE) of the radiation for production of adverse cellular effects. Accuracy in dose equivalent is therefore dependent on the accuracy of particle LET spectra measurements, particularly in the LET region above 3.5 keV/μm where Q rises above 1 for ionizing particles.

A series of passive integrating measurements of environmental radiation using passive dosimeters located both inside and outside the Mir Space Station is being carried out as part of the NASA-Mir Phase 1B Science Program. These measurements will significantly expand the U. S. data base at the 51.6° inclination orbit, provide detailed information on shielding effects, allow intercomparison of dosimetric methods and provide data for extensive testing of model calculations. Measurements of linear energy transfer (LET) spectra are being carried out the range of 5 to 1250 keV/μm using CR-39 plastic nuclear track detectors (PNTDs) in six area passive dosimeters (APDs) located throughout the interior of the Mir Station and at one location on the external surface of the Mir station. Total absorbed dose is being measured using thermoluminescent detectors (TLDs) included inside each APD. The combination of absorbed doses and LET spectra measured with the PNTDs will allow total dose, total dose equivalent and average Quality Factor (QF) to be determined for each APD location inside Mir. Comparisons will be made between LET spectra, dose and dose equivalent measured with different types of dosimeters including the APDs and other dosimeters currently in use on Mir. In addition to the USF detectors, each APD contains a detector stack from Institute of Medical and Biomedical Problems (IMBP) in Moscow. Comparisons between these detectors will be for identical shielding geometry. APDs are also placed near the NASA-JSC TEPC microdosimeter and other Russian flight dosimeters. The agreement between dosimeter measurements by different countries and institutions is an important consideration in establishing a broad, reliable data base for the radiation environment in space. Comparisons will be made between three sets of measurements corresponding to the NASA-2/Mir-21, NASA-3/Mir-22 and NASA-4/Mir-23 missions to determine the change in radiation environment over time. The measurements will be made with identical APDs in the same locations on the Mir. Comparisons will be made between LET spectra and absorbed dose measurements and corresponding calculations based on environmental models and transport codes. Shielding at the four APD locations inside the Mir have been determined with the aid of a three dimensional mass model. Trapped particle models (AP8, AE8), galactic cosmic ray energy spectra models (Creme96) and codes for propagating radiation through matter (HETC) can tested in these comparisons.

The use of TLDs to measure absorbed dose and CR-39 PNTDs to measure LET spectra has become standard on missions of the U. S. Space Shuttle. APDs similar to those deployed aboard Mir during the NASA/Mir Phase-1B Science Program have been included on several Space Shuttle missions since the inception of the program. These dosimeters have also been used aboard the Long Duration Exposure Facility, the ESA Eureca retrievable spacecraft, numerous Russian/Soviet Biocosmos missions and aboard Mir itself during the Mir-18 mission. Figure 1 and 2 show the locations of the four APDs in the Core module and the 2 APDs in the Kvant 2 module. In addition, Figure 2 shows the location of the External Dosimeter Array (EDA) mounted on the outside of the Kvant 2 module during the NASA-4/Mir-23 and NASA-5/Mir-24 missions.

II. Program 1 - Internal Experiment:

1. Absorbed Dose Measurements:

To date, TLDs from the NASA-2/Mir-21, NASA-3/Mir-22 and NASA-4/Mir-23 APDs have been processed and readout. Table 1 shows the dose rates, and dose equivalent rates where available, measured using TLDs for each of the six APDs exposed during each of the three missions. Figures 3, 4, and 5 show dose and dose rate for the six APDs during each of the three NASA/Mir missions. During the NASA-2/Mir-21 mission varied from 268 μGy/d for APD-6 in the Kvant 2 module to 422 μGy/d for APD-3 at the base of the control console in the Core module. The average dose rate for each of the five APDs returned by STS-79 was 324 μGy/d. Similarly, dose equivalent rate varied from 513 μSv/d in APD-6 to 710 μSv/d in APD-3. It should be noted that the dose equivalent rate measurements were determined using results from both the TLDs and PNTDs and thus represent a corrected total dose equivalent rate while the dose rates reported here are only from the measurements made in TLDs and thus underreport the dose contribution from high (>5 keV/μm) LET particles.

Table 1 also includes dose rates measured at the six APD locations during the NASA-3/Mir-22 and NASA-4/Mir-23 missions. Dose equivalent rates are presently not available and are awaiting completion of the PNTD analysis for these two missions. Dose rate for the NASA-3/Mir-22 mission ranged from 265 μGy/d in APD-6 to 378 μGy/d in APD-3. Dose rate for the NASA-4/Mir-22 mission ranged from 273 μGy/d in APD-5 located on the EVA airlock bulkhead in the Kvant-2 module to 361 μGy/d for APD-3. Shielding differences in the six APD locations are immediately apparent with APD-3, in the Core module beneath the command console under the lowest shielding and APD-6 on ceiling panel #303 in the Kvant 2 module being under greatest shielding. The APD-6 location is surrounded by a large amount of equipment and is located immediately beneath the two gyrodynes atop which the EDA was mounted. The other conclusion that can be drawn from Table 1 is that dose rates decreased for each of the successive NASA/Mir missions. The most likely reason for this a decrease in altitude of the Mir

Station during this time period. Dose rate decreases exponentially with decreasing altitude in the South Atlantic Anomaly. Due to atmospheric drag, the Mir continually loses altitude and must periodically be reboosted to a higher altitude. Records of when reboosts occurred and the altitude of Mir as a function of time are currently be consulted to verify this interpretation.

2. LET Spectra Measurements:

The PNTDs from the NASA-2/Mir-21 APDs have been processed and analyzed. CR-39 PNTD layers oriented in the x, y, and z planes of each APD were selected for processing. One layer from each plane was chemically etched in 6.25 N NaOH solution at 50°C for 36 hours, while a second layer from each plane was chemically etched in 6.25 N NaOH solution at 50°C for 168 hours. Track data from each of the two layers at a given orientation were measured and the differential LET spectra for each detector was plotted. Detectors processed for 168 hours reveal the low-LET component for the spectrum while the 36 hour processed detectors reveal the higher LET component. The high LET component includes short-range tracks (~10 μm) produced by the target fragmentation of primary high energy protons on the carbon and oxygen nuclei of the detector. The two differential LET curves were then combined to produce one spectrum for each of the three measured axes. These three integral LET spectra were then folded together to produce an average integral LET spectra for the given APD. High LET results from the CR-39 PNTDs have been used to corrected doses measured in TLDs and to determine total dose equivalent and dose equivalent rate at each APD location.

Figure 6 shows the integral LET flux spectra measured for each of the five APDs included in the NASA-2/Mir-21 mission while Figures 7 through 11 show each individual LET flux spectrum and the Lineal Energy Transfer spectrum measured by the JSC-TEPC during the initial part of the NASA-2/Mir-21 mission. There is close agreement between the five curves throughout the entire measured range from 5 to 1000 keV/μm. The curve from APD-6 lies somewhat below the others for LET ≥ 100 keV/μm. This is consistent with the lower dose rate measured in APD-6. The high LET region is primarily made up of short-range (~10 μm) secondary particles produced in target fragmentation events when primary protons interact with the C and O nuclei of the detector. Greater shielding at the APD-6 location is seen in the decrease in total dose and in the relative number of target fragment events.

Most of the curves are seen to change slope between 250 and 350 keV/μm as indicated by the arrow in Figure 6. This knee occurs at the approximate maximum LET for α-particles. Below this knee, most of the LET spectra is believed to be made up of protons and α-particles produced in target fragmentation events. Above ~300 keV/μm, the spectrum is caused by GCR and by heavier target fragments. The lower rate of production of these heavier fragments relative to protons and α-particles is most likely responsible for the steeper slope above ~300 keV/μm.

Averaged dose rate spectra for each APD were generated from the averaged flux results and are shown in Figure 12. The PNTD dose rate results for LET ≥5 keV/μm are given in Table 2. Dose equivalent rate spectra were calculated using the ICRP-26 quality factors and the results are also presented in Figure 13 and Table 2. The effective quality factor as a function of LET for each APD has been calculated from the integral dose and dose equivalent results and the results are shown in Figure 14. As seen in the LET flux spectrum, there is good agreement between all the dose rate and dose equivalent rate curves, though the spectrum measured for APD-6 falls somewhat below the others. As stated earlier, this is most likely due to the APD-6 location in the Kvant 2 module being more heavily shielded than the other four locations in the Core module.

Integral LET Flux Spectra have also been measured for two of the APDs flown on the NASA-3/Mir-22 mission. Figure 15 shows the integral LET flux spectra measured in APD-1 during the NASA-3/Mir-22 mission along with the same measurement for the NASA-2/Mir-21 mission. Figure 16 shows the integral LET flux spectra measured in APD-2 during the NASA-3/Mir-22 and NASA-2/Mir-21 missions. The two measurements agree within limits of experimental error in the high LET region (>100 keV/μm). For the APD-1 location, the NASA-3/Mir-21 curve lies slightly above the NASA-2/Mir-21 curve at lower LET. For the APD-2 location the two curves nearly lie atop of one another at lower LET.

3. Conclusions from Internal Measurements:

The TLDs used in this work were of the TLD-700 (^{7}LiF) type. The efficiency of dose measurement for this type of TLD decreases at a known rate with increasing LET. The TLD measured doses must therefore be corrected to give the true doses. The PNTD dose measurements are about 100% efficient above 5 keV/μm, while the TLD-700 efficiency decreases above this value. PNTD dose measurements can therefore be used to correct the TLD doses. PNTD dose results are combined with the known TLD-700 efficiency function to give an accurate dose result for each APD location. The initial and corrected TLD doses and total dose rates are given in Table 3. Total dose equivalent and dose equivalent rates were then determined from the corrected doses and are given in Table 4. As reported above, Dose equivalent rates varied from 512.8 μSv/d for APD-6 in the Kvant 2 module to 709.9 μSv/d for APD-3 at the base of the Command Console in the Core module. As with the measured dose rates and LET spectra, differences in dose equivalent rates are most probably due to shielding differences.

The dose rates measured in the APDs on the Mir Space Station ranged from 268 to 422 μGy/d with and average of 324 μGy/d. A similar measurement of dose rate was made during the Mir-18 mission, between February 28 and July 7, 1995 in an APD located near the APD-2 location in the Core module. The Mir-18 dose rate was fount to be 264 μGy/d, somewhat less than the 288 μGy/d dose rate measured in the same location during the NASA-2/Mir-21 mission. Since the shielding for this location most likely remained more or less constant between the two missions, the differences in the dose rate probably reflect a difference in altitude of the Mir station during the two missions. The Mir is periodically boosted to higher altitude to count the constant loss of altitude due to atmospheric drag. At higher altitudes, the Mir passes through a larger portion of the South Atlantic Anomaly and receives a greater exposure from the trapped protons in the region. Mir was most likely at a higher altitude during the NASA-2/Mir-21 mission than during the Mir- 18 mission.

A comparison of the Mir-21 JSC-TEPC integral Lineal Energy Transfer flux spectrum with the PNTD results shows that the spectra from both types of detector are comparable over almost the entire LET range shown. The deviation of the results below about 20 keV/μm is due to a fall off in the detection efficiency of the PNTDs. Differences above about 100 keV/μm are expected due to the differing chemical compositions of the two types of detector media. Above 100 keV/μm, most of the spectrum is produced by proton-induced, short-range, high-LET target fragments. Target fragment production is dependent on the elemental composition of the medium through with the primary protons pass. The greater concentration of C and O nuclei per unit volume in the CR-39 PNTDs versus the sensitive volume of the TEPC leads to the higher signal in the LET region above 100 keV/μm.

A comparison of the 4π averaged integral flux spectra is shown in Figure 6. As can be seen the results are in agreement with each other within the limits of experimental error. The APD-6 result falls below the others above about 200 keV/μm, and is probably due to shielding differences. This comparison shows that the radiation field for LETs 25 keV/μm is similar despite the differing locations of the APDs. The same comparison also shows that each spectrum displays a change in slope (knee) at about 300 keV/μm. This knee is found to be a feature of the secondary particle spectrum. These events are secondary target fragments which are generated by the inelastic scattering of primary protons and a-particles within the detector medium. Particles with charge above 2 tend to be found with LETs above 300 keV/μm, while those with charge 2 and below tend to have LETs less than this value. The integral dose and dose equivalent results have been used to calculate the effective quality factor. The effective quality factor for LETs 25 keV/μm in each case is about 9. This demonstrates the significance of short range high LET target fragments to dose equivalent.

Readout and analysis of the remain NASA-3/Mir-22 PNTDs and the NASA-4/Mir-23 PNTDs is ongoing and expected to be completed during the final year of this experiment. Dose and dose equivalent values from the PNTDs will be combined with dose results from the TLDs to provide mission averaged dose and dose equivalent rates. Additional comparisons between results from the APD detectors and other detectors will be carried out. It is also hoped that model calculations can be carried out for the four Base Block APD locations so that comparisons can be made with actual measurements.

III. Program -2 External Experiment:

Dose rate was measured as a function of shielding depth using stacks of thin TLD-700 detectors mounted on the external surface of the Kvant 2. Stacks of thin (0.0036") and regular (0.035") TLDs were mounted inside Lexan holders which were in turn mounted inside specially designed aluminum blocks. The aluminum blocks were in turn mounted on a removable aluminum tray (pictured in Figure 17). The removable tray, referred to as the External Dosimeter Array (EDA) also contained similar thin TLD stacks from the Institute of Biomedical Problems (IBMP) in Moscow and several sets of plastic nuclear tracks detectors (PNTD) from both USF and IBMP. The EDA was stored inside the Mir station before and after external exposure. It was deployed during an EVA and mounted in the specially designed STD platform on the outside surface of the Kvant 2 module. The STD platform is mounted above two gyrodynes as pictured in Figure 2. It is partially blocked by a solar array attached to the Mir Base Block.

A similar measurement was carried out on the STD platform in June 1991. While the EDA tray was of the same design during both experiments, the composition and arrangement of passive detectors and their holders differed between the two exposures. The original EDA used during the June 1991 experiment was never returned to Earth, and no drawings or photographs of the original experiment could be located. Thus there are probably small differences in shielding between the two exposures. Differences in the two exposures also arise from the fact that the Mir only possessed the Base Block, Kvant 1, Kvant 2 and Kristal modules during the 1991 exposure. By 1997, the Spektr and Priroda modules had been added and the arrangement of the older modules was modified to accommodate the newer ones. In addition, it is possible that the station orientation was different for the two exposure times. Nevertheless, these measurements were as nearly as possible carried out under identical conditions except for solar epoch. Duration of the exposures, time spent inside Mir both before and after exposure, etc. were beyond the control of the P.I.

The first measurement was made in June 1991, roughly corresponding to Solar Maximum. This set of exposures lasted approximately 27 days. The second set of measurements was carried out beginning on 29 April 1997 and ending on 5 September 1997, a period roughly corresponding to Solar Minimum. Total duration of the second set of exposure is was 130 days. Figure 18 shows dose rate as a function of shielding depth in TLD-700. As expected, the measurements made at solar maximum lie well above the measurements made during solar minimum. At greater shielding depth (above 1 g/cm^2) the two sets of measurements begin to level off and intersect, due to the fact that shielding from the sides of the stack is now of the same magnitude as the shielding from above. Differences in shielding between the two experiments, especially shielding immediately surrounding that stacks, most likely account for the differences in shape between the two sets of measurements.

A calculation for the June 1991 measurement was made using the AP8MAX trapped proton and AE8MAX trapped electron models. This curve also lies well below the June 1991 measured curves. The large magnitude of the June 1991 measurements can be attributed to the short-lived trapped belts produced from the October 1989 Solar Particle Events. Calculation for the 1997 measurements have yet to be carried out, but since these exposures were made during a period near Solar Minimum and there were no significant SPEs during this time, agreement between measurements and calculations is expected to be better.

IV. Conclusions

During the final year of the NASA/Mir Phase 1B Environmental Radiation Measurements on the Mir Station Experiment, the PNTDs included in the EDA will be processed, readout and analyzed. The remaining PNTDs from the NASA-3/Mir-22 and NASA-4/Mir-23 APDs including the APD that remained aboard Mir during both the NASA-4/Mir-23 and NASA-5/Mir-24 missions will be readout and analyzed.

Comparisons will be made both with other measurements from detectors flown on the Mir Station and with model calculations. Corrected dose rates and dose equivalent rates will be determined for all the APDs. Comparisons of dose and dose equivalent rates as functions of location within Mir, individual mission, and the Mir altitude will be made. These results will be included in the final report for the NASA/Mir Phase 1B Environmental Radiation Measurements on the Mir Station Experiment.

V. References

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Table 1. Dose Rate and Dose Equivalent Rate Measured
Aboard Mir Space Station 1996-1997

Detector	Location		Mir-21 /NASA-2 3/22/96 – 9/26/96 188.2 days	Mir-22/NASA-3 9/16/96 – 1/22/97 127.2 days	Mir-23/NASA-4 1 /12/97 – 5/22/97 130.1 days
APD-1	Base Block	Dose Rate	328 ± 10 μGy/d	309 ± 9 μGy/d	323 ± 1.0 μGy/d
	Door to Engineer's Cabin	D.E. Rate	576 ± 2 μSv/d	being analyzed	being analyzed
APD-2	Base Block	Dose Rate	288 ± 9 μGy/d	273 ± 8 μGy/d	287 ± 8 μGy/d
	Ceiling Panel #325	D.E. Rate	551 ± 2 μSv/d	being analyzed	being analyzed
APD-3	Base Block beneath	Dose Rate	407 ± 13 μGy/d	378 ± 12 μGy/d	361 ± 11 μGy/d
	Command Console	D.E. Rate	710 ± 2 μSv/d	being analyzed	being analyzed
APD-4	Base Block	Dose Rate	324 ± 10 μGy/d	343 ± 7 μGy/d†	300 ± 9 μGy/d
	near Window #3	D.E. Rate	639 ± 2 μSv/d	being analyzed	being analyzed
APD-5	Kvant 2	Dose Rate	319 ± 10 μGy/d*	421 ± 13 μGy/d‡	273 ± 8 μGy/d**
	Airlock bulkhead	D.E. Rate	being analyzed	being analyzed	being analyzed
APD-6	Kvant 2	Dose Rate	271 ± 9 lμGy/d	265 ± 8 μGy/d	285 ± 8 μGy/d††
	Ceiling Panel #303	D.E. Rate	513 ± 1 μSv/d	being analyzed	to be analyzed
EDA	STD Platform on outer	Dose Rate			D(SD)
	surface of Kvant 2	D.E. Rate			to be analyzed

D.E. Rate = Dose Equivalent Rate.
D(SD) = dose measured as function of shielding depth.

*Flight Movement APD (STS-79) exposed for 10 days.
†Flight Movement APD (STS-81) exposed for 10 days.
‡Exposed for 305.3 days on both NASA-2 and NASA-3 missions.
**Exposed for 247.4 days on both NASA-3 and NASA-4 missions.
††Exposed for 267.5 days on both NASA-4 and NASA-5 missions.

Table 2. Dose and Dose Equivalent Rates from particles with LET ≥5 keV/μm measured in CR-39 PNTDs.

APD No.	Dose Rate (LET ≥5 keV/μm) (μGy/d)	Dose Equivalent Rate (LET ≥5 keV/μm) (μSv/d)
1	26.3 ± 1.2	267 ± 18
2	29.7 ± 0.9	284 ± 12
3	31.9 ± 0.8	326 ± 11
4	38.0 ± 1.0	345 ± 14
6	31.4 ± 0.8	265 ± 9

Table 3. Doses measure by TLDs, corrected TLD doses and corrected dose rates for the five NASA-2/Mir-21 APDs.

APD No.	TLD Dose (mGy)	Corrected Dose (mGy)	Corrected Dose Rate (μGy/d)
1	61.7 ± 1.9	63.1 ± 1.9	334 ± 10
2	54.2 ± 1.6	55.7 ± 1.6	295 ± 8
3	76.6 ± 2.4	78.3 ± 2.4	400 ± 12
4	60.8 ± 1.9	62.6 ± 1.9	320 ± 10
6	51.1 ± 1.6	52.5 ± 1.6	278 ± 9

Table 4. Total dose equivalent and dose equivalent rates for the five NASA-2/Mir-21 APDs.

APD No	Dose Equivalent (mSv)	Dose Equivalent Rate (μSv/d)
1	108.4 ± 0.4	576 ± 2
2	103.6 ± 0.3	551 ± 2
3	133.6 ± 0.3	710 ± 2
4	120.3 ± 0.3	639 ± 2
6	96.5 ± 0.2	513 ± 1

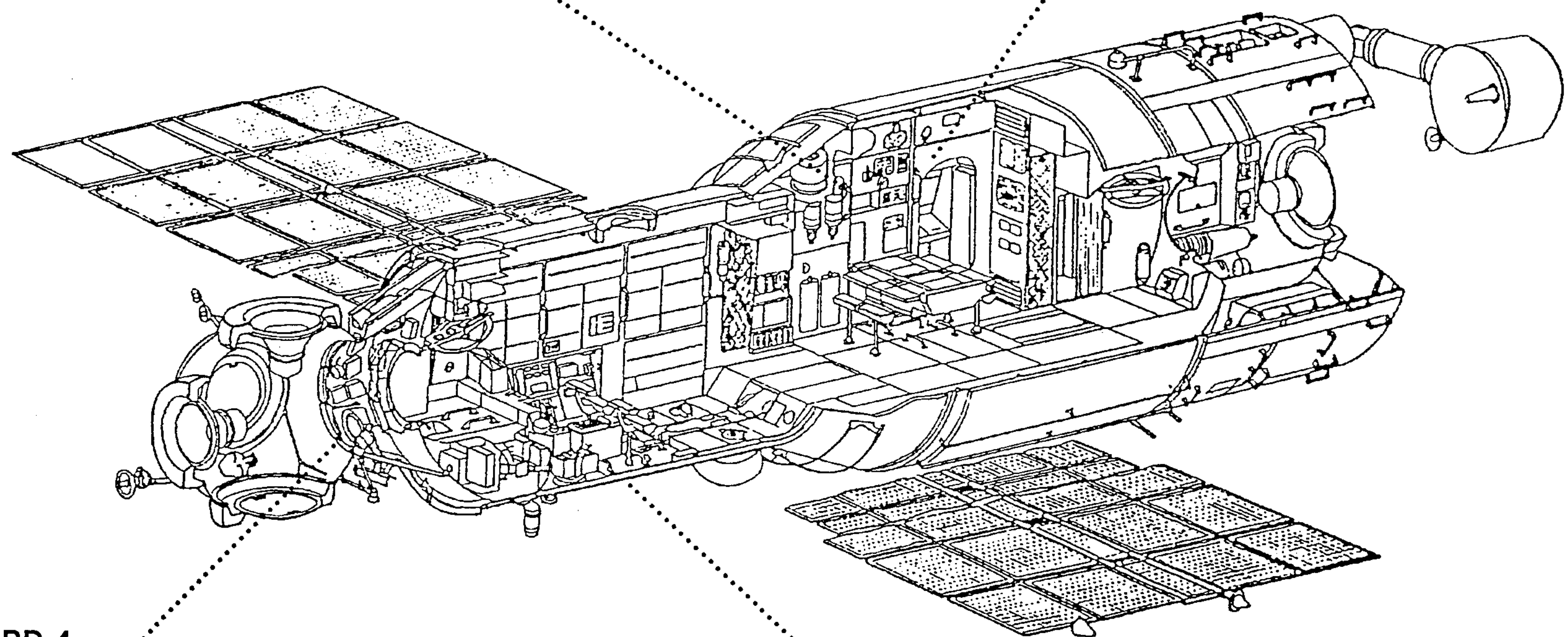


Figure 1. Locations of four APDs inside Core Module

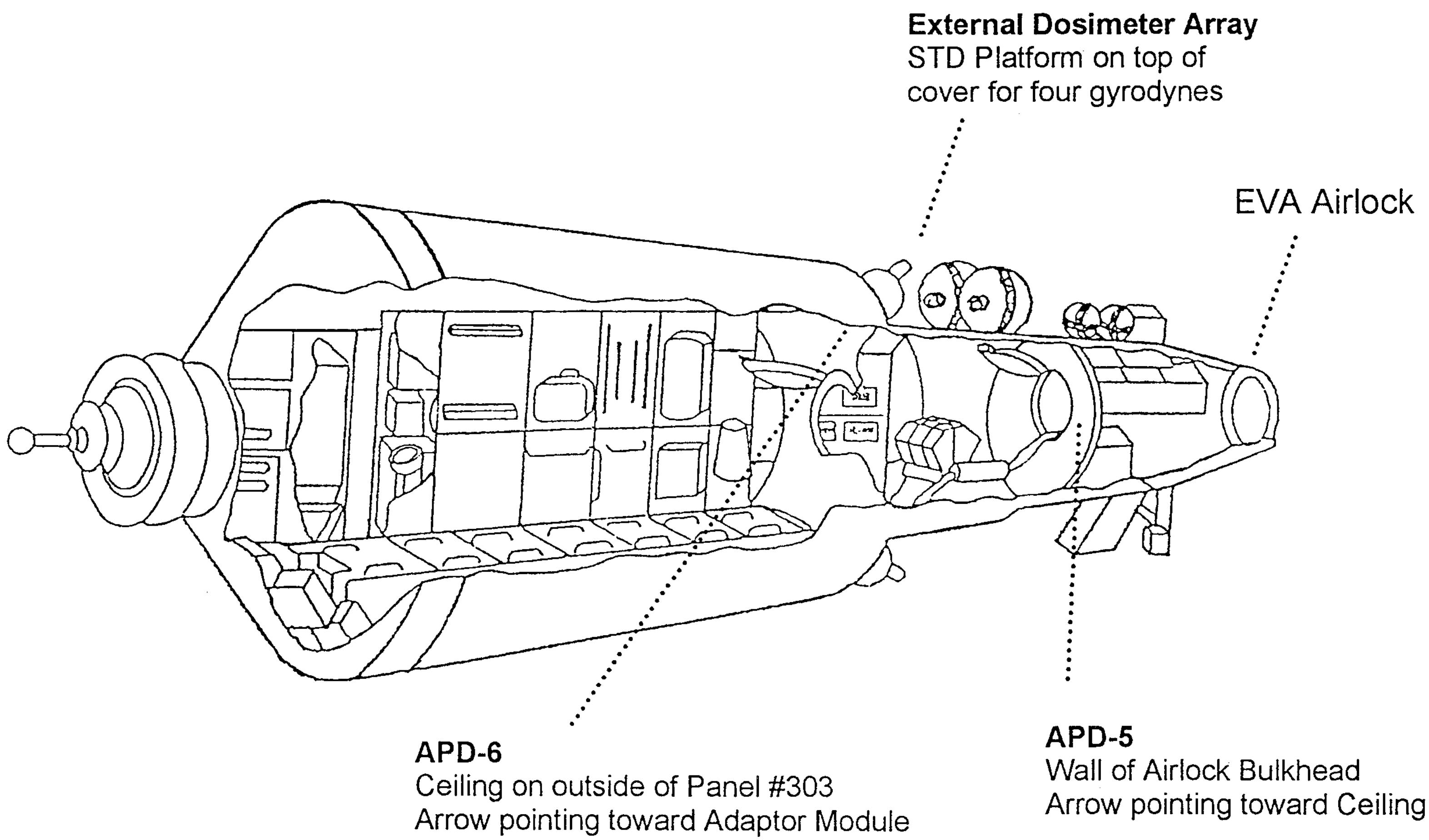
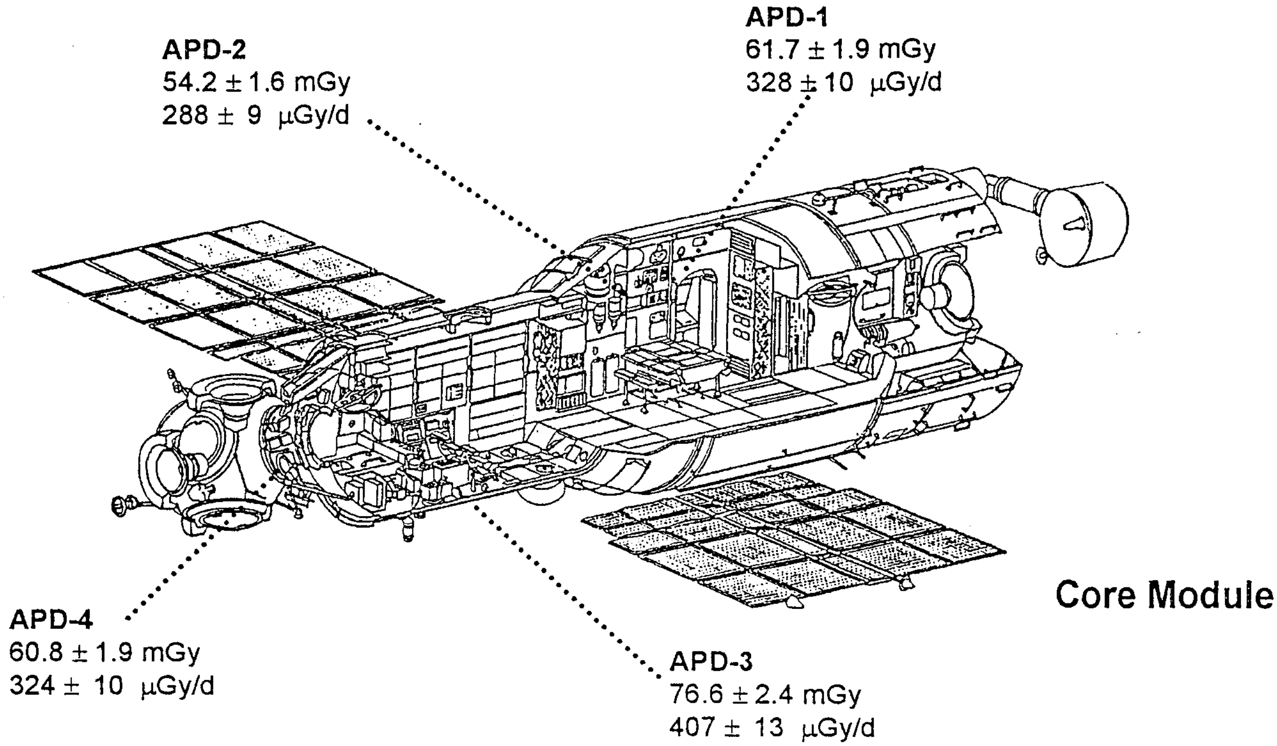
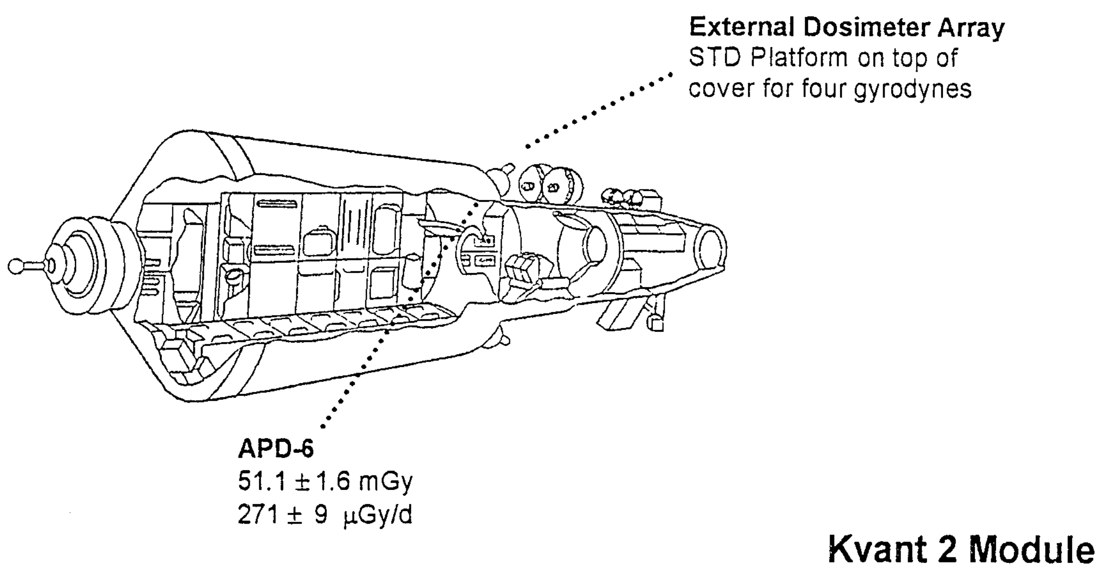


Figure 2. Locations of two APDs inside Kvant 2 Module and STD Platform outside Kvant 2 Module





Flight Movement APD (STS-79)
3.23 ± 0.1 mGy
319 ± 10 μGy/d

Figure 3. Dose and Dose Rates Measured inside
Mir Station during the NASA-2/Mir21 Mission
by the USF Environmental Radiation Measurements Experiment
22 March - 26 September 1996 (188.2 days)

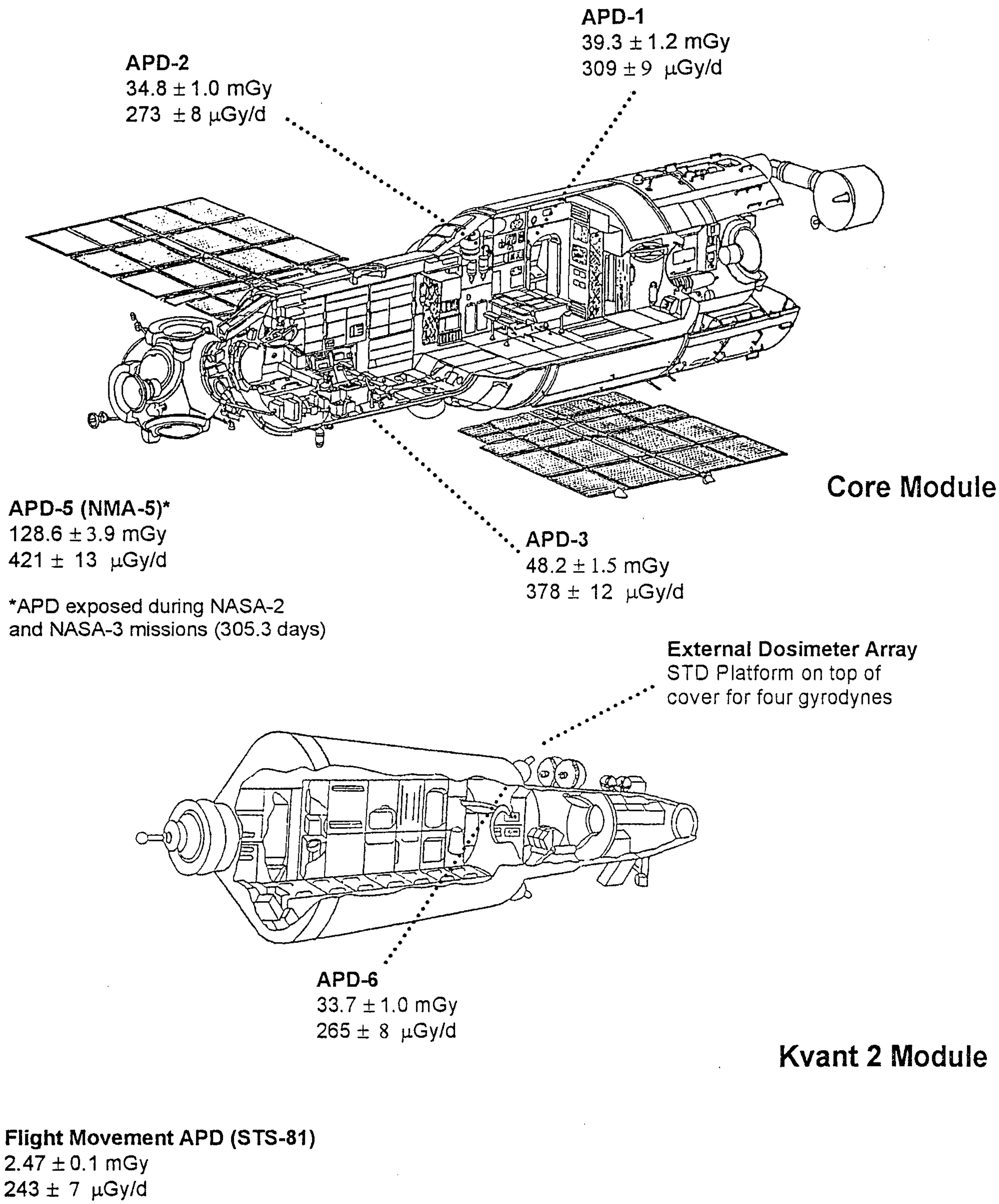
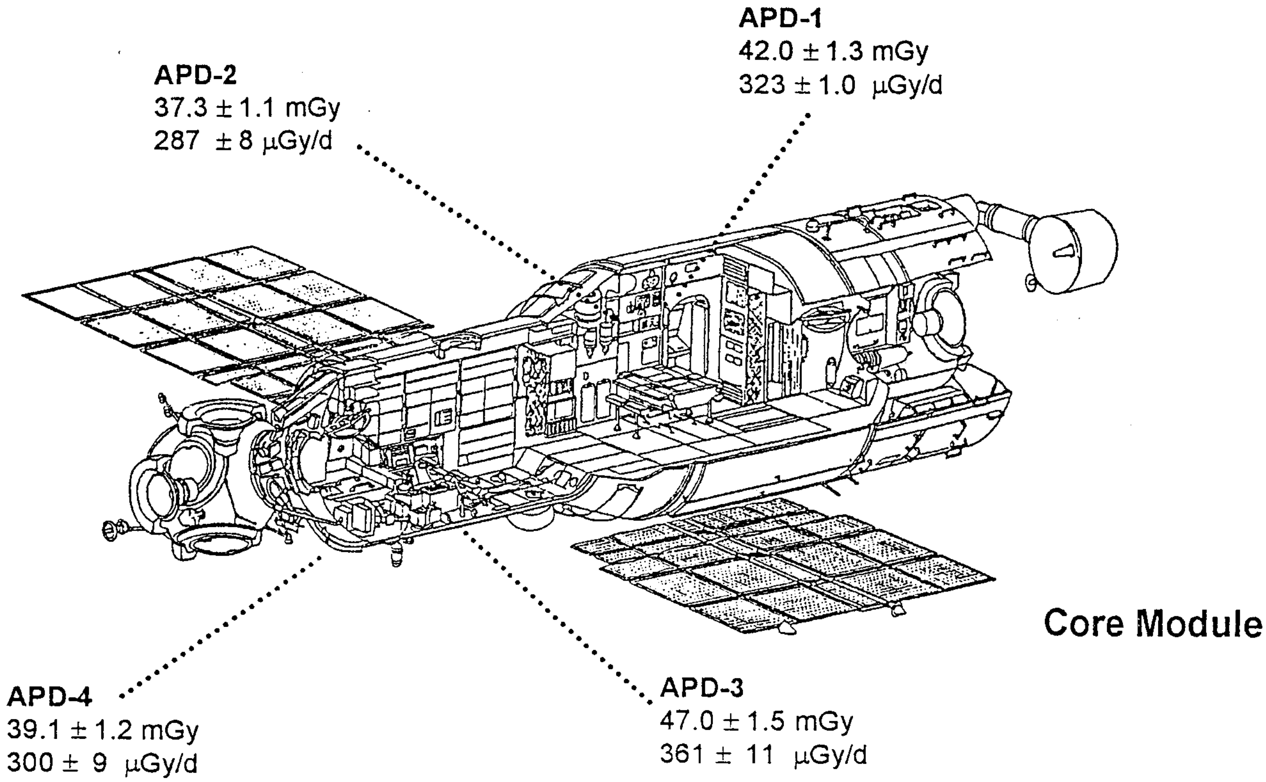


Figure 4. Dose and Dose Rates Measured inside
Mir Station during the NASA-3/Mir22 Mission
by the USF Environmental Radiation Measurements Experiment
16 September 1996 - 22 January 1997 (127.2 days)



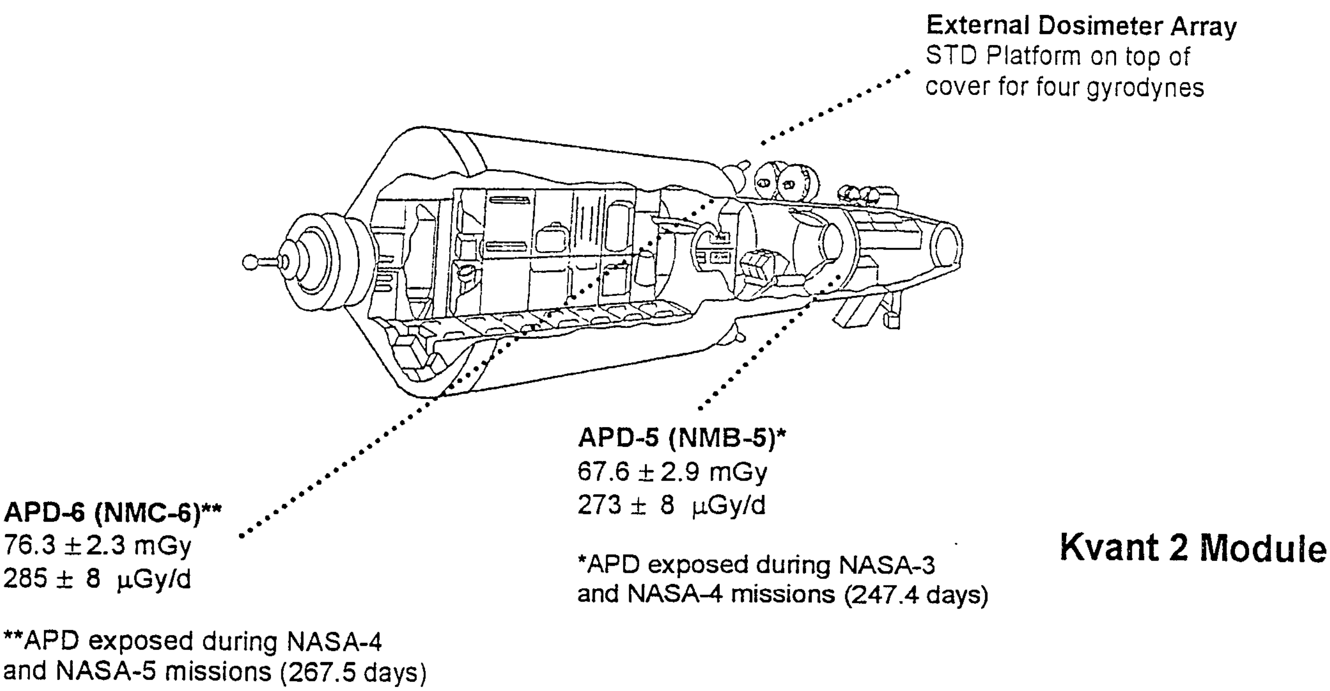


Figure 5. Dose and Dose Rates Measured inside Mir Station during the NASA-4/Mir23 Mission by the USF Environmental Radiation Measurements Experiment 12 January - 22 May 1997 (130.1 days)

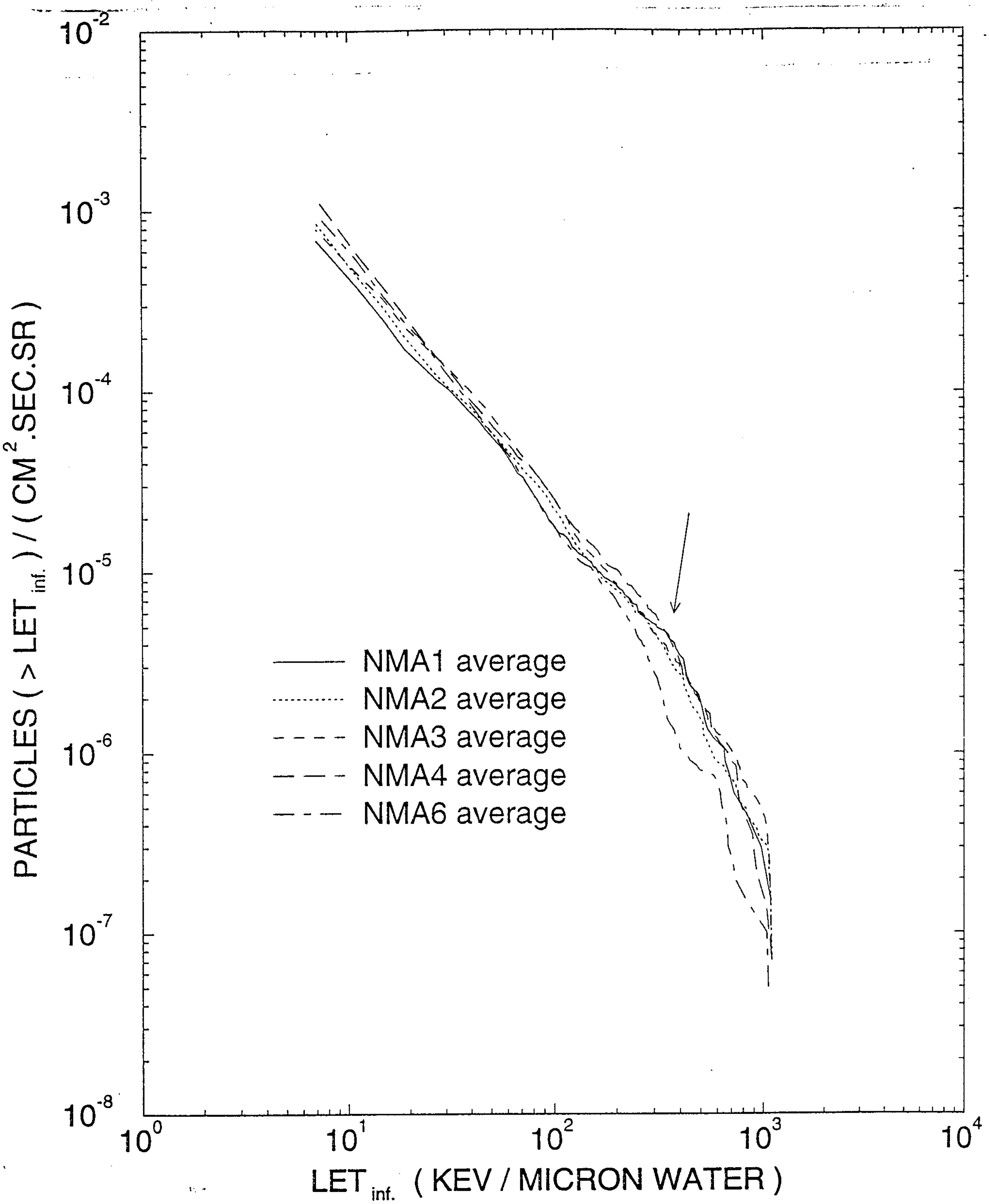


Figure 6. Integral LET Flux Spectra measured inside the Mir Station during the NASA-2/Mir-21 Mission by the USF Environmental Radiation Measurements Experiment: 22 March – 26 September 1996.

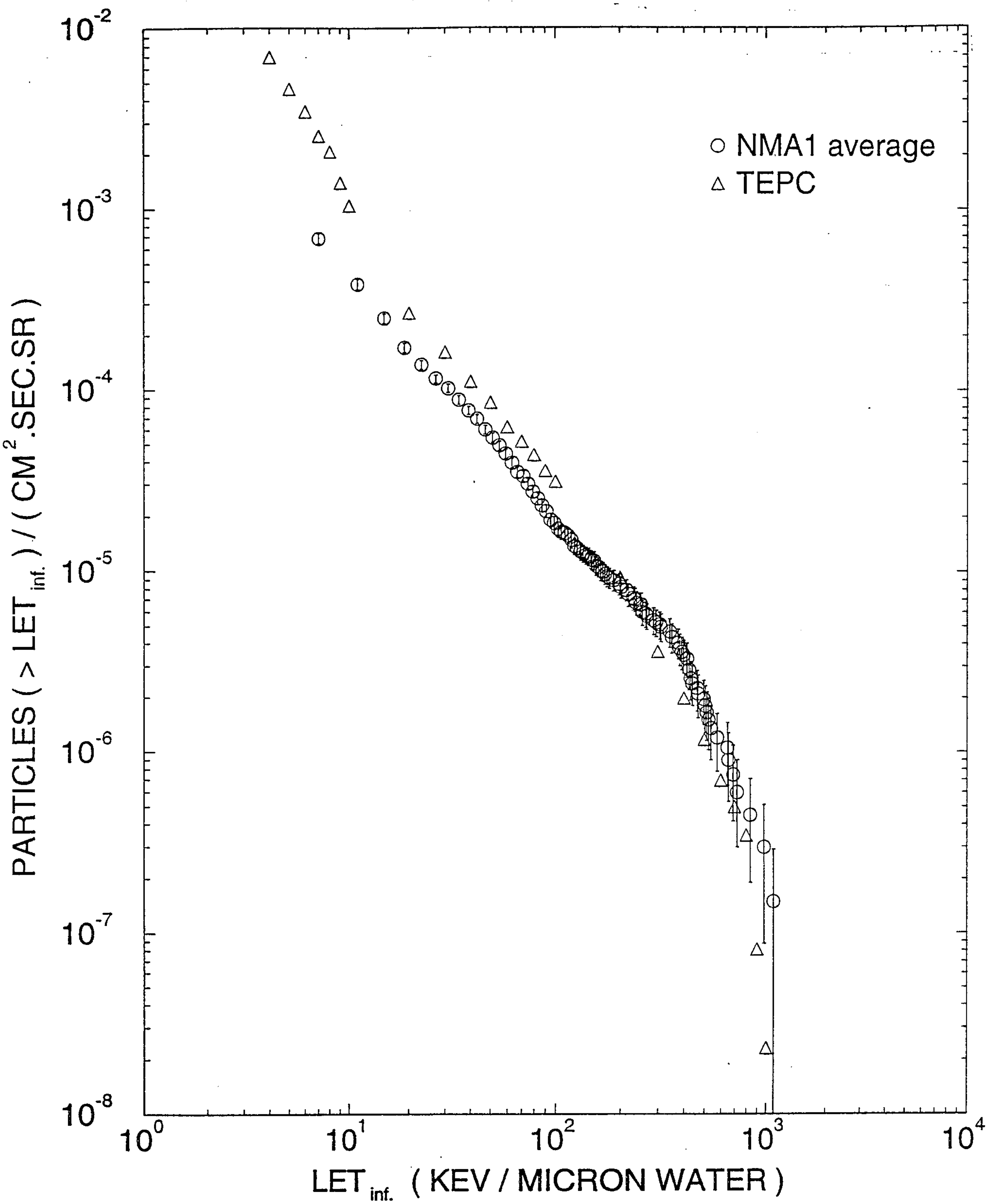


Figure 7. Average integral LET flux spectra for APD-1 and for the JSC-TEPC measured in the Base Block of the Mir Station during the NASA-2/Mir-21 mission: 22 March – 26 September 1996.

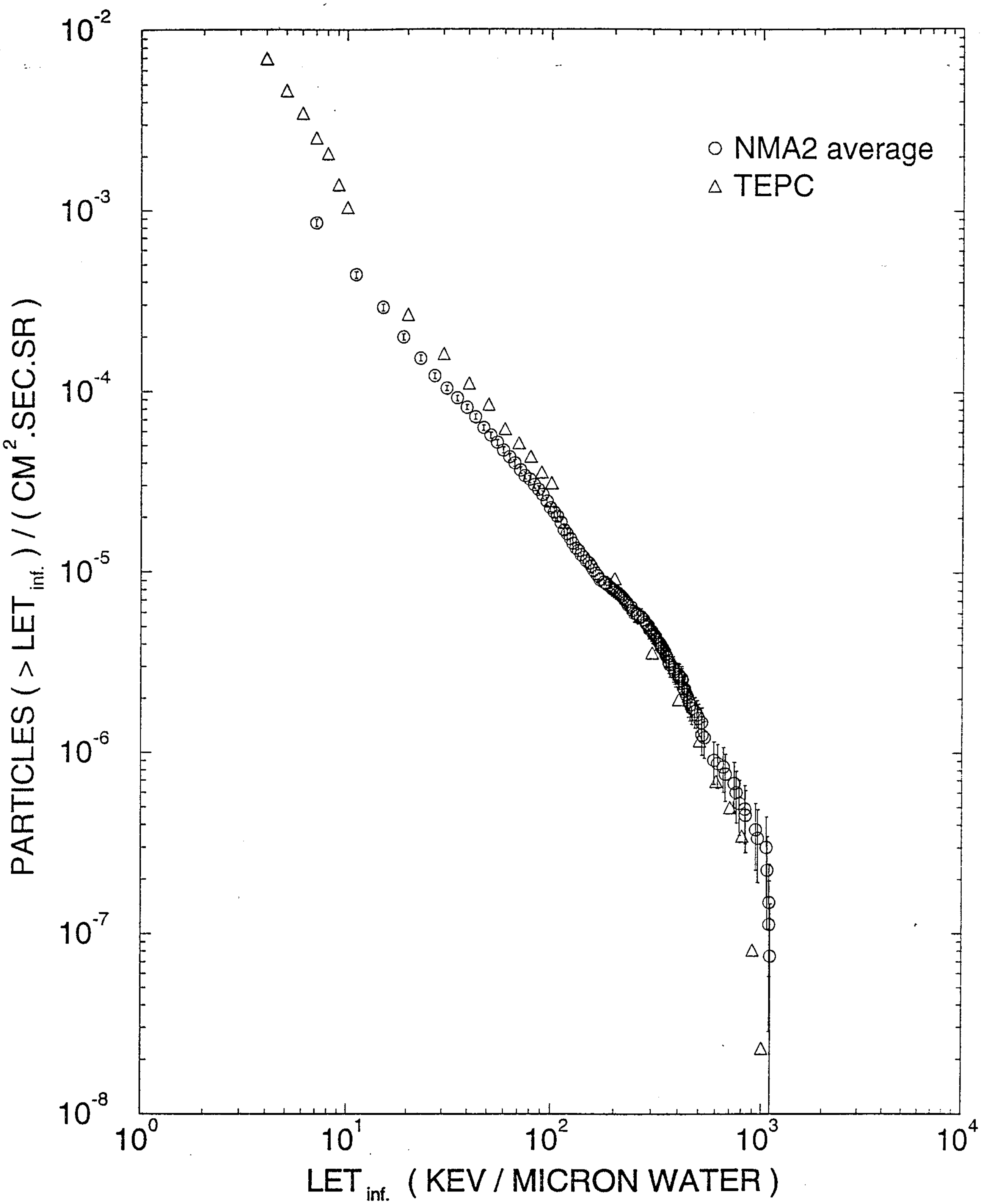


Figure 8. Average integral LET flux spectra for APD-2 and for the JSC-TEPC measured in the Base Block of the Mir Station during the NASA-2/Mir-21 mission: 22 March – 26 September 1996.

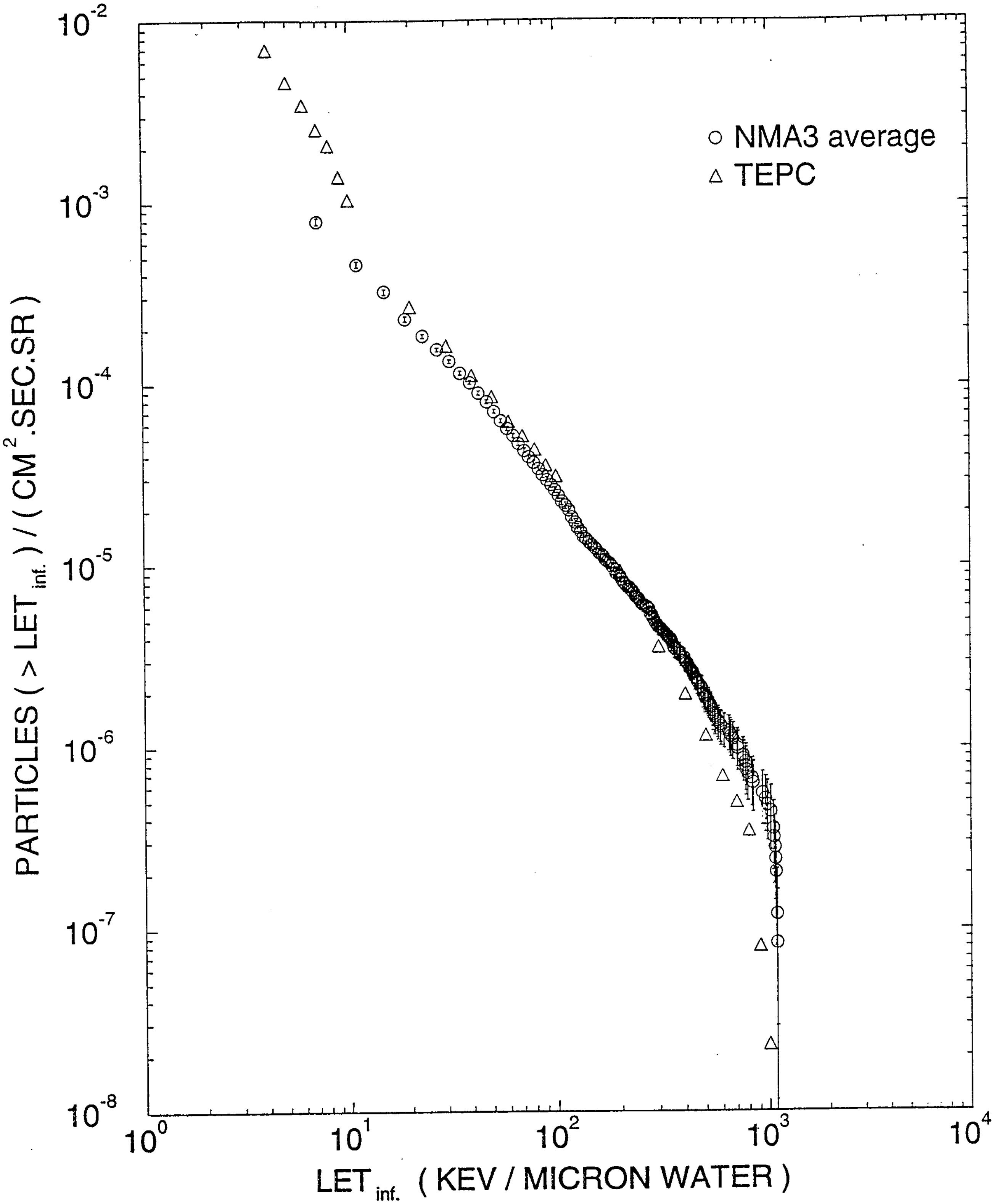


Figure 9. Average integral LET flux spectra for APD-3 and for the JSC-TEPC measured in the Base Block of the Mir Station during the NASA-2/Mir-21 mission: 22 March – 26 September 1996.

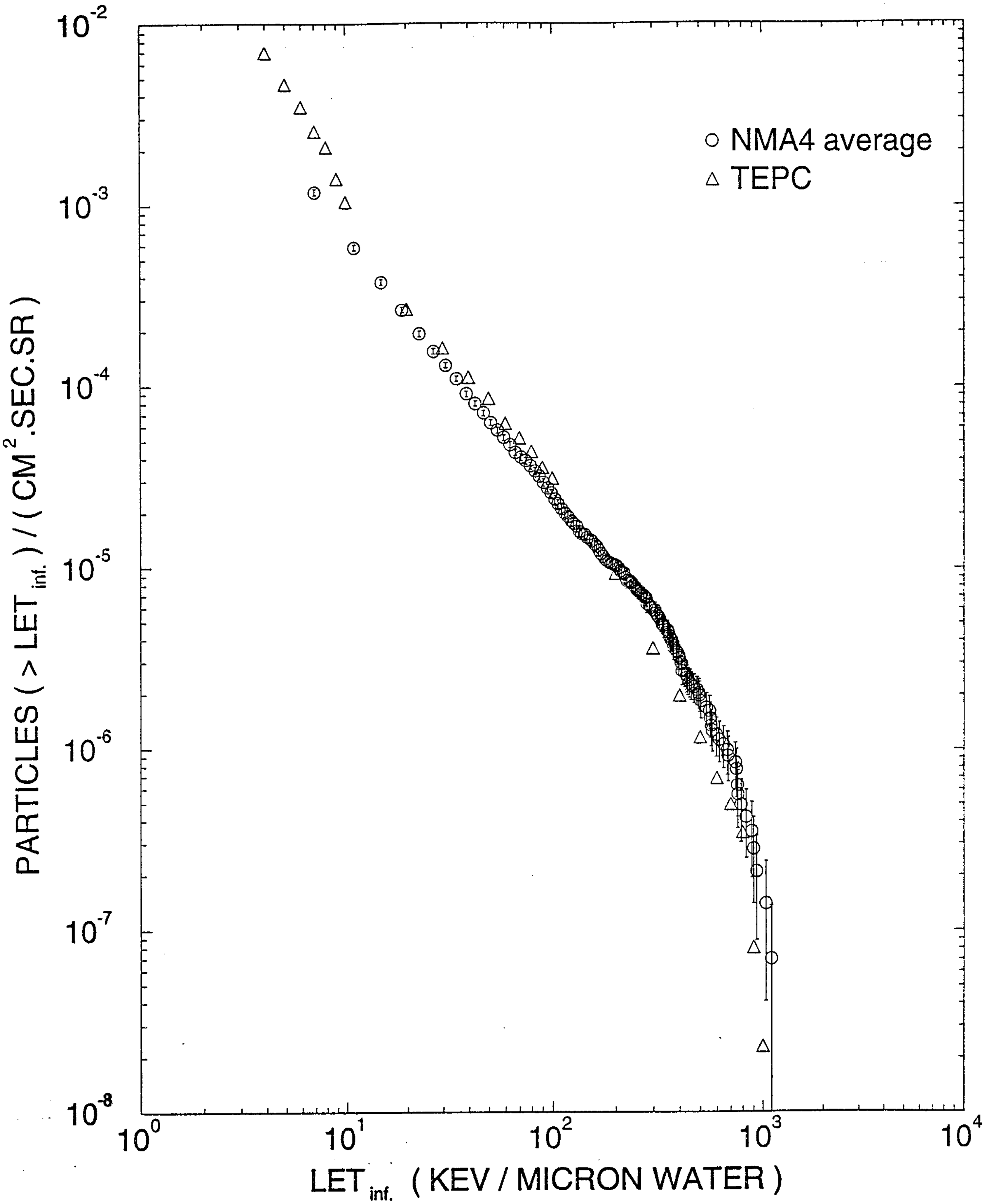


Figure 10. Average integral LET flux spectra for APD-4 and for the JSC-TEPC measured in the Base Block of the Mir Station during the NASA-2/Mir-21 mission: 22 March – 26 September 1996.

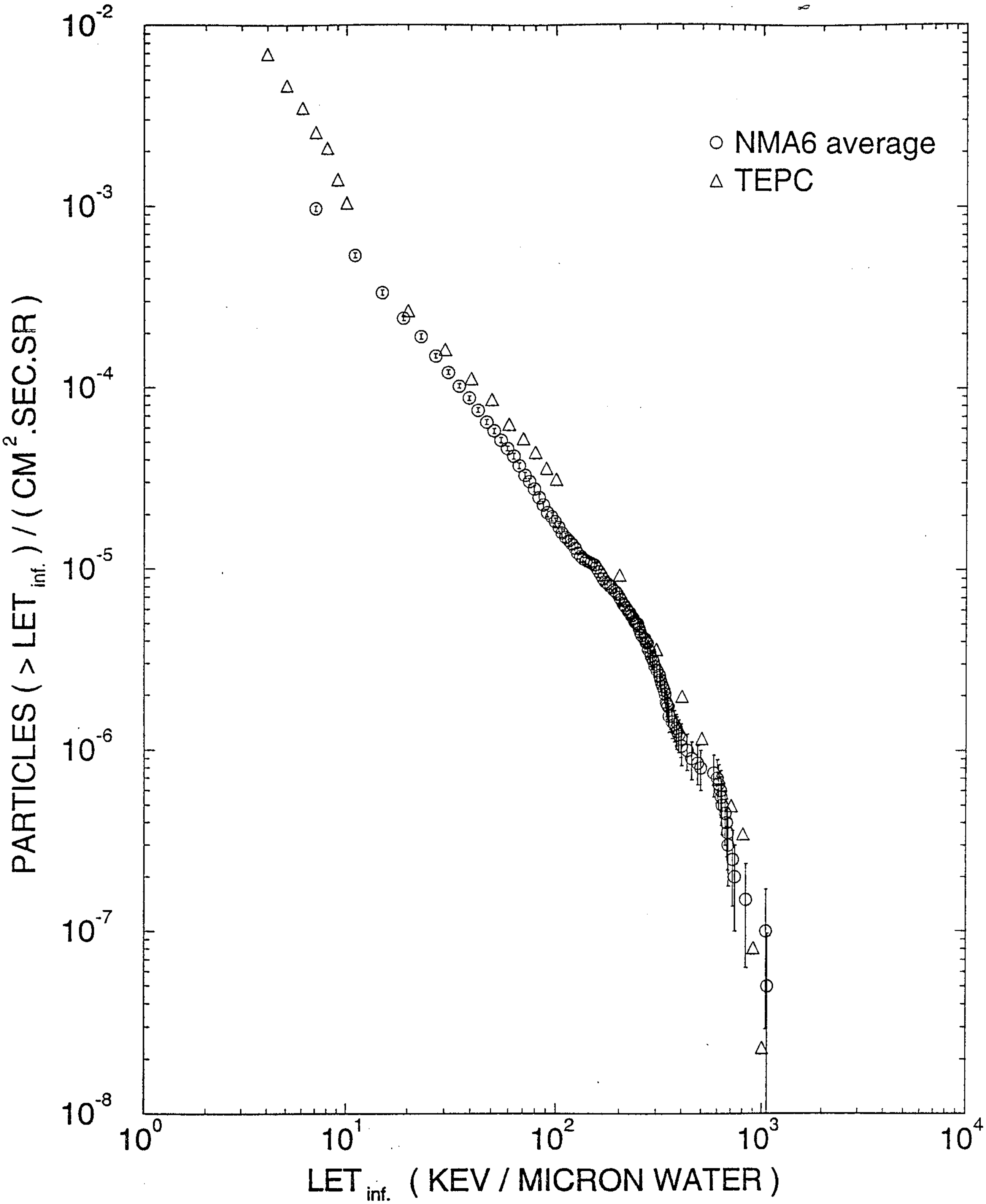


Figure 11. Average integral LET flux spectra for APD-6 and for the JSC-TEPC measured in the Base Block of the Mir Station during the NASA-2/Mir-21 mission: 22 March – 26 September 1996.

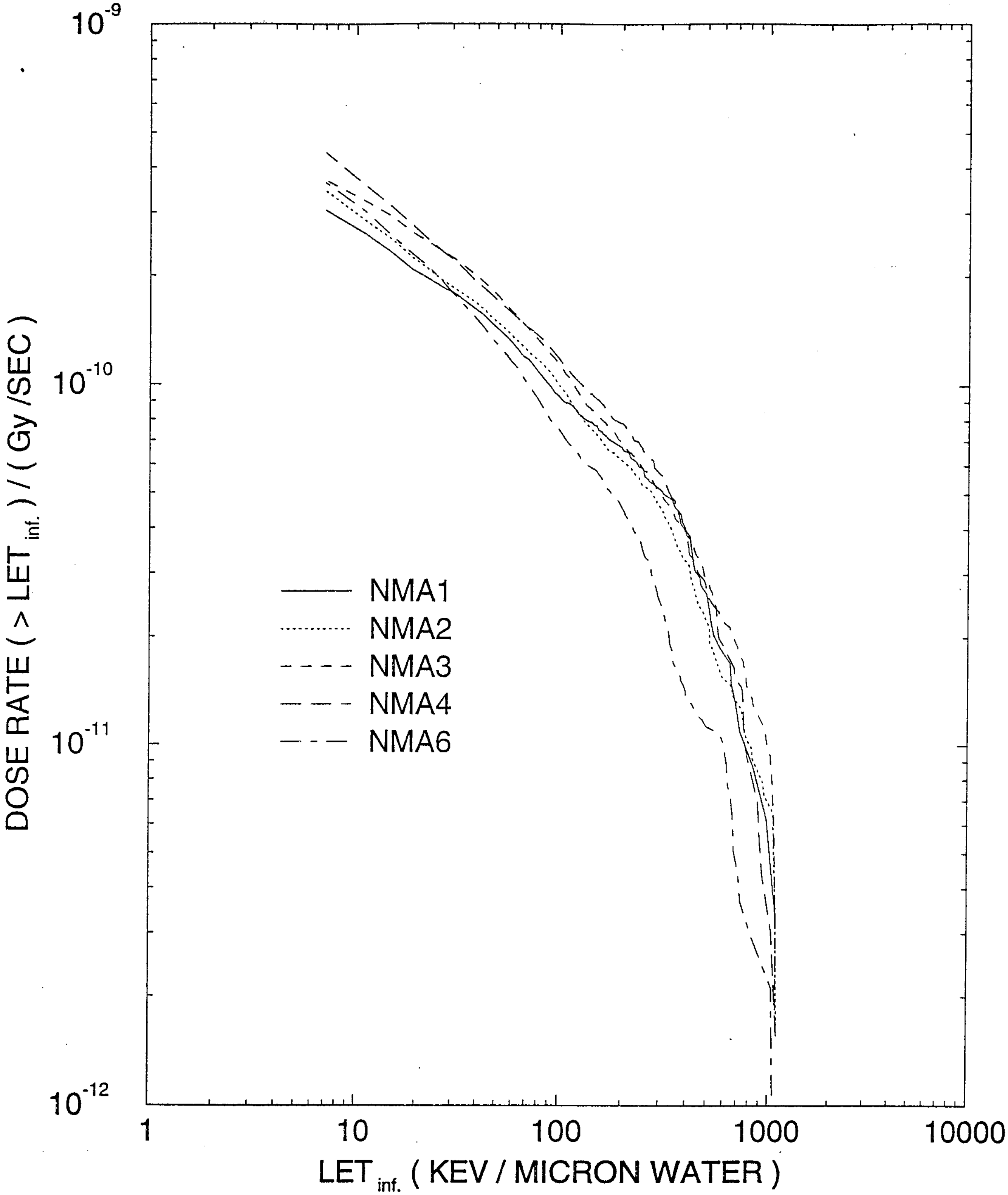


Figure 12. Integral LET dose rate spectra measured inside the Mir Station during the NASA-2/Mir-21 Mission by the USF Environmental Radiation Measurements Experiment: 22 March – 26 September 1996.

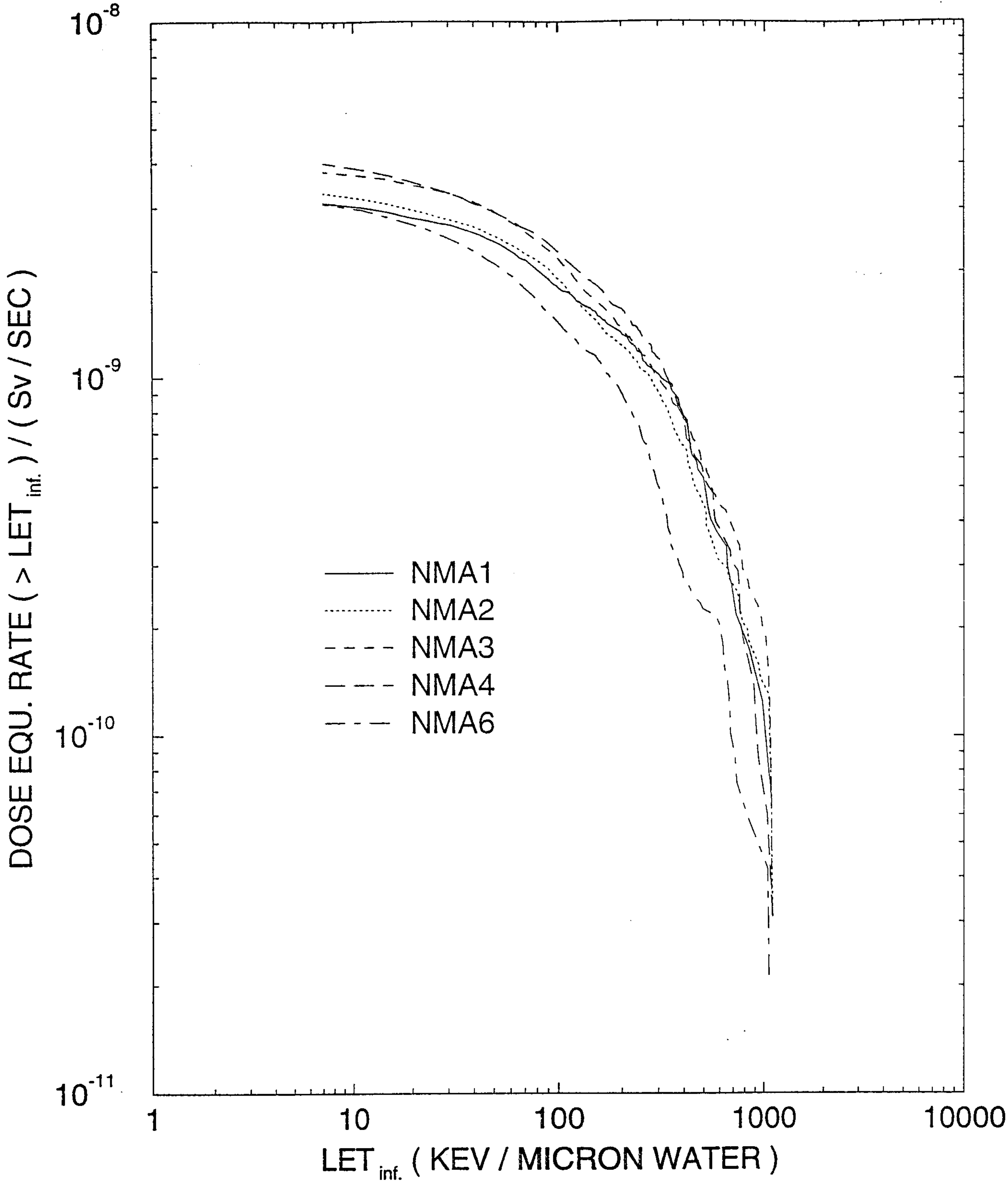


Figure 13. Integral LET dose equivalent rate spectra measured inside the Mir Station during the NASA-2/Mir-21 Mission by the USF Environmental Radiation Measurements Experiment: 22 March – 26 September 1996.

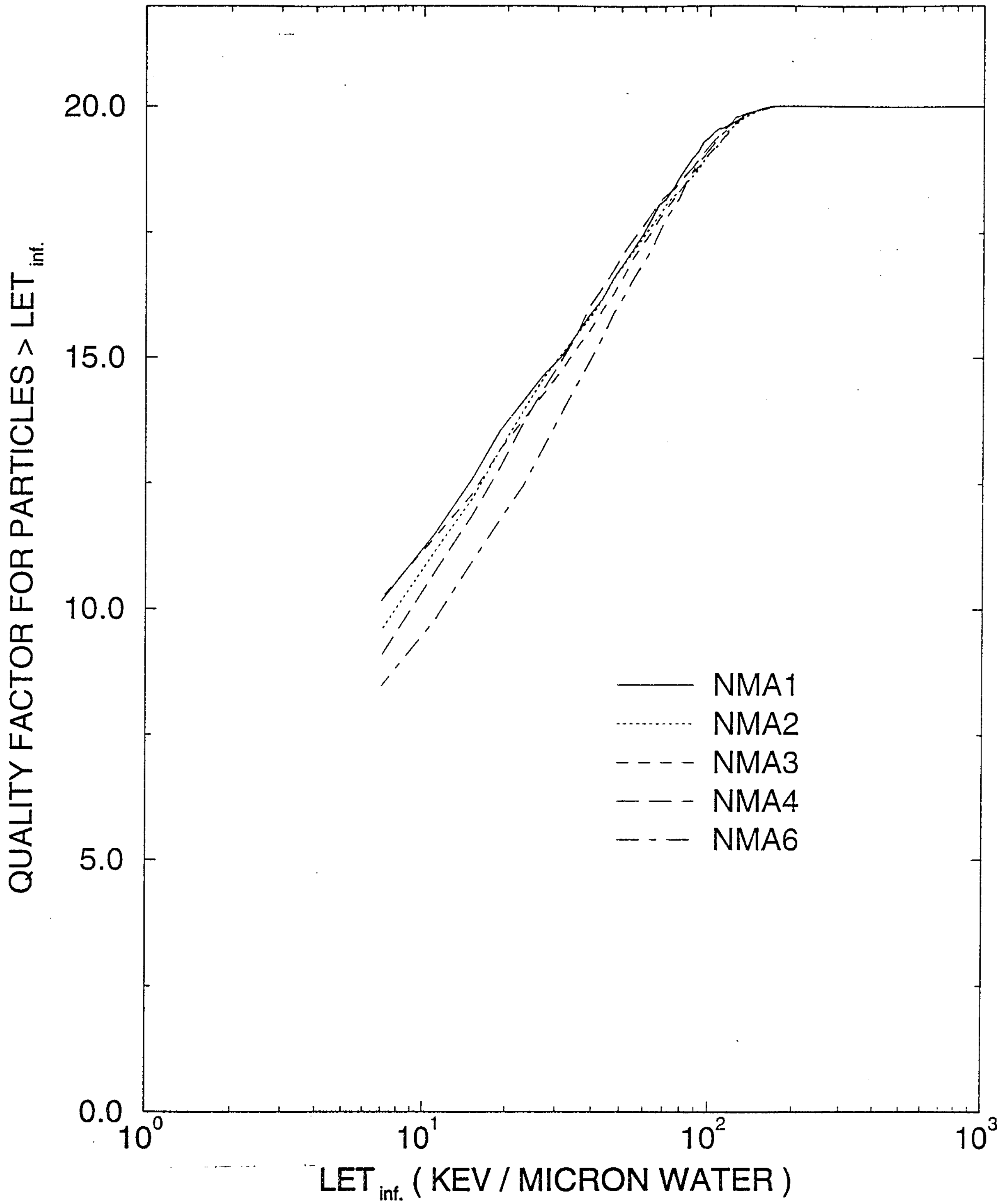


Figure 14. Integral LET average quality factor spectra measured inside the Mir Station during the NASA-2/Mir-21 Mission by the USF Environmental Radiation Measurements Experiment: 22 March – 26 September 1996.

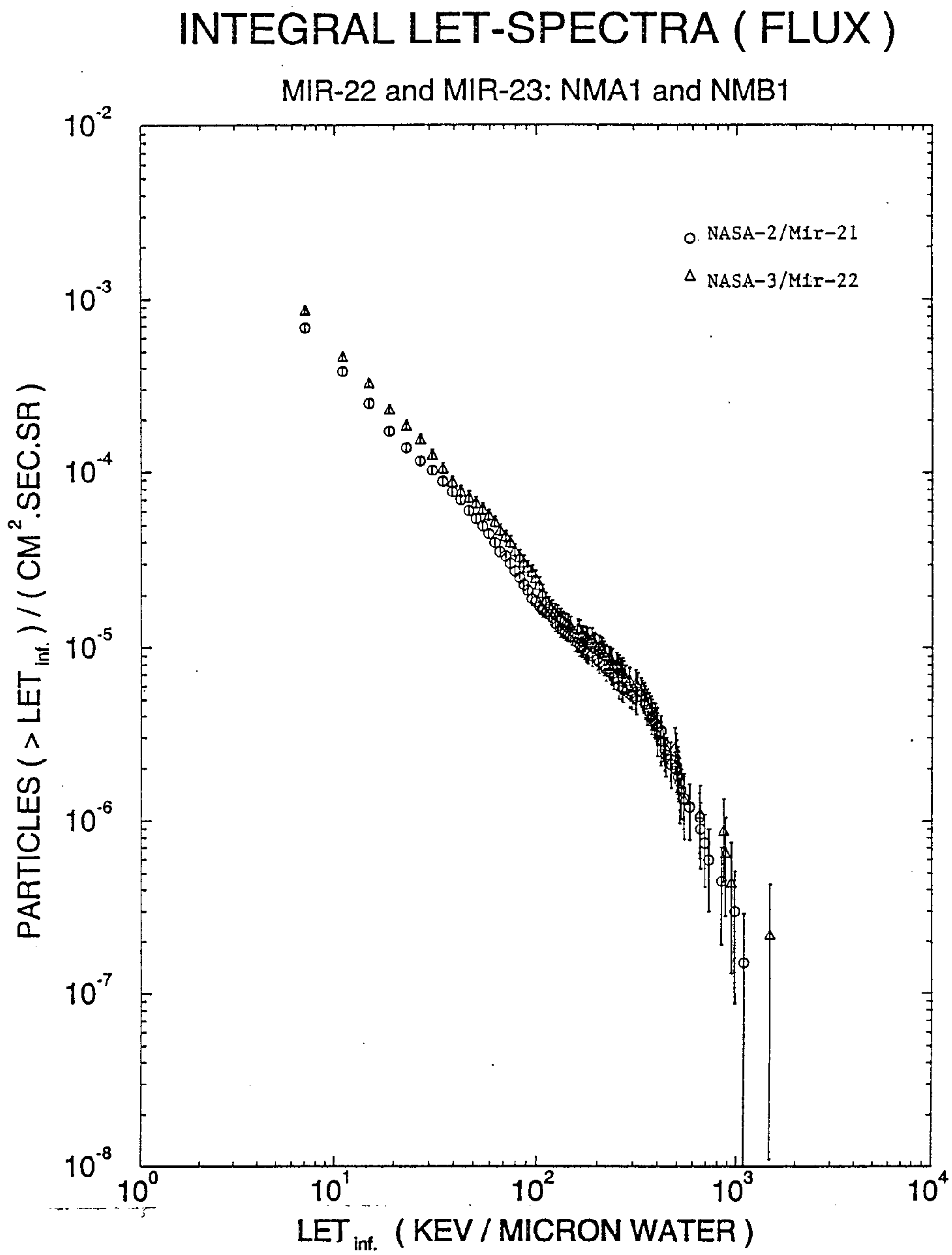


Figure 15. Integral LET flux spectra measured in the APD-1 location during the NASA-3/Mir-21 mission, 16 September 1996 – 22 January 1997, and comparison with LET spectra measured during the NASA-2/Mir-21 mission.

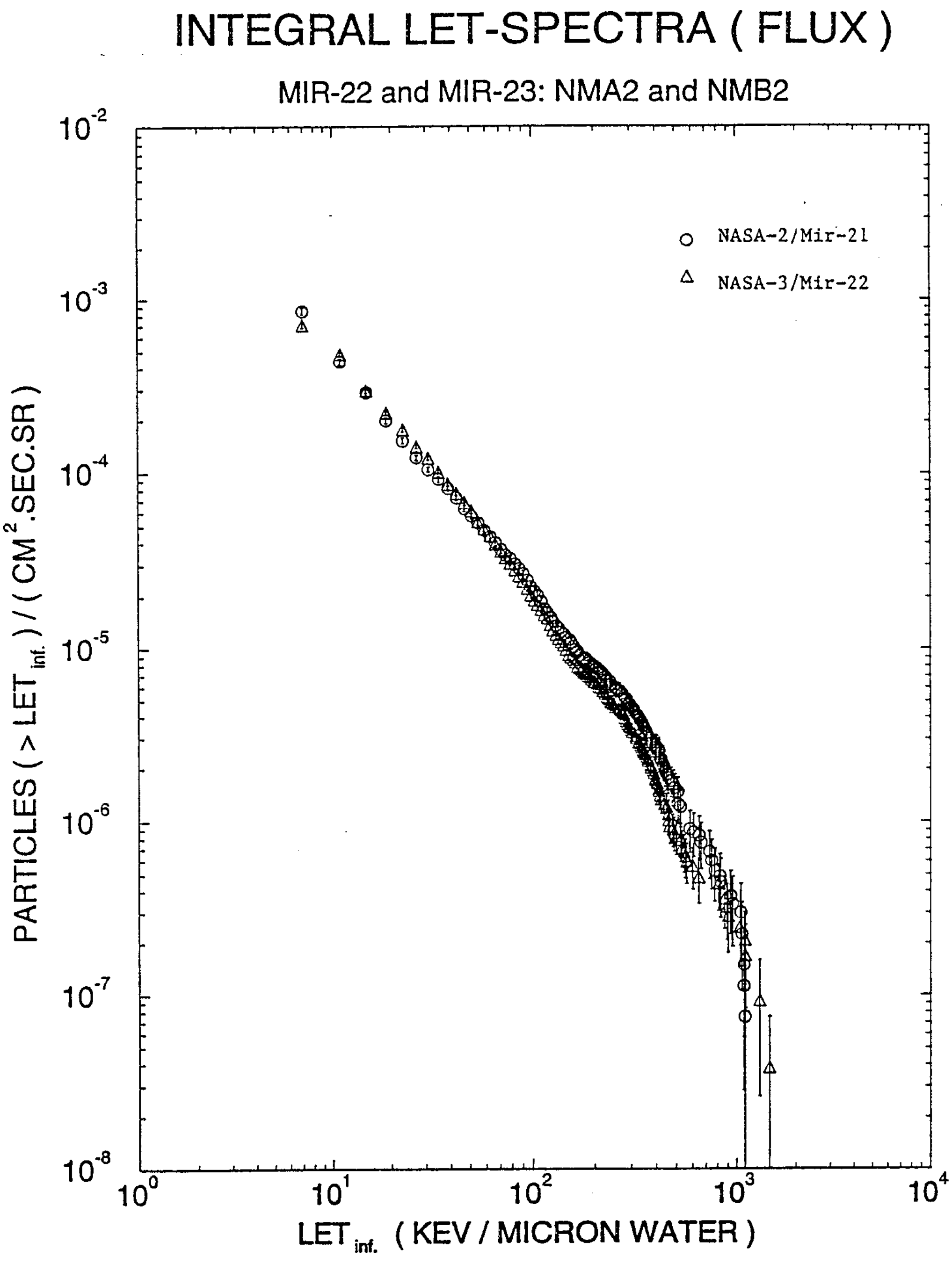


Figure 16. Integral LET flux spectra measured in the APD-2 location during the NASA-3/Mir-21 mission, 16 September 1996 – 22 January 1997, and comparison with LET spectra measured during the NASA-2/Mir-21 mission.

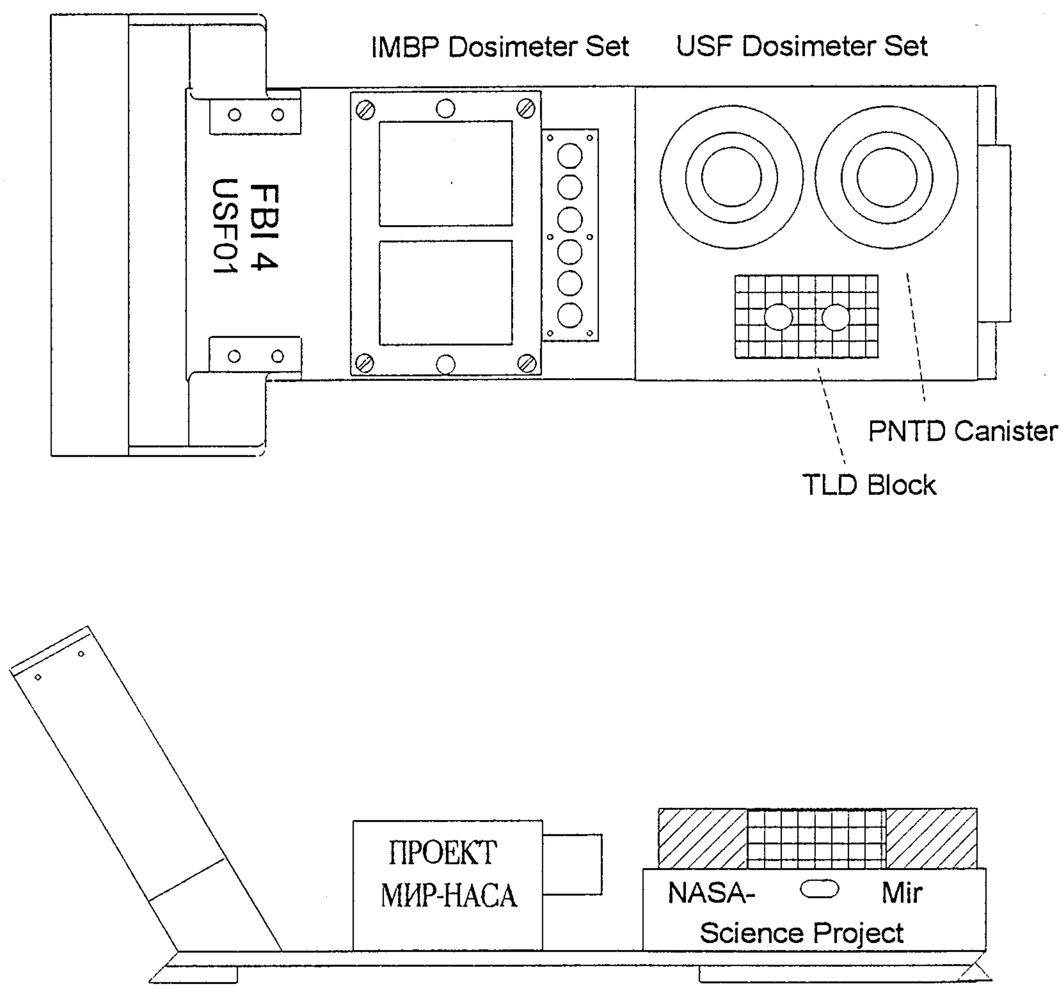


Figure 17. Top and side views of the External Dosimeter Array (EDA) in the deployed configuration.

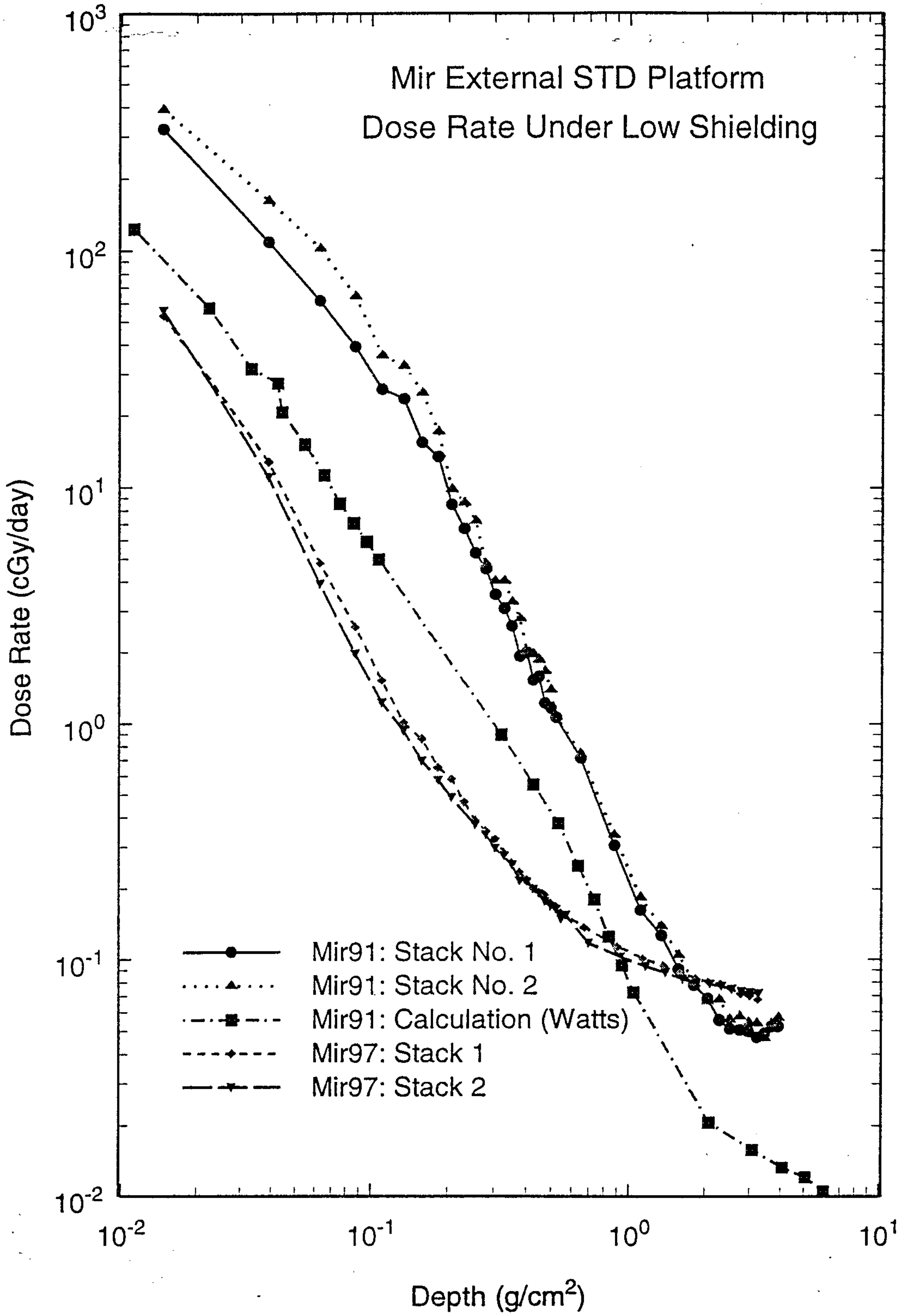


Figure 18. Dose rate as a function of shielding depth in TLD-700 measured in the EDA on the external surface of the Kvant-2 module during the NASA-4/Mir-23 and NASA-5/Mir-24 missions: 29 April – 5 September 1997.