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FUTURE RADIATION MEASUREMENTS IN LOW EARTH ORBIT

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SUMMARY

The first LDEF mission has demonstrated the value of the LDEF concept for deep surveys of the space radiation environment. This paper discusses the kinds of measurements that could be done on a second LDEF mission. Ideas are discussed for experiments which: a) capitalize on the discoveries from LDEF I; b) take advantage of LDEF's unique capabilities and c) extend the investigations begun on LDEF I. These ideas have been gleaned from investigators on LDEF I and others interested in the space radiation environment. They include new approaches to the investigation of ^{7}Be that was discovered on LDEF I, concepts to obtain further information on the ionic charge state of cosmic rays and other energetic particles in space and other ideas to extend the investigations begun on LDEF I.

INTRODUCTION

LDEF I carried several space radiation experiments and additional experiments were done with parts of the satellite that were not originally intended as experimental material. This first mission demonstrated the utility of LDEF for certain kinds of investigations of the space radiation environment.

The first LDEF mission produced the discovery of large amounts of cosmogenic ^{7}Be in the exoatmosphere at 310 km altitude[1]. LDEF I also produced further evidence for heavy ions trapped in the earth's magnetic field[2] which may be due to trapped anomalous cosmic rays[3] or some new source of trapped heavy ions. The mission also demonstrated that three axis stabilized satellites are non-uniformly irradiated by trapped protons due to the guiding center asymmetry in low earth orbit[4]. This mission furthered the investigation of the ionic charge state of cosmic rays and is helping to demonstrate the richness of this new information channel on ionizing particle radiation[5].

The world's largest cosmic ray experiment was onboard LDEF I. This experiment returned information of the elemental composition of the heaviest and rarest cosmic ray nuclei[6]. The LDEF satellite also carried experiments to measure the radiation doses and LET spectra on LDEF[7,8,9,10]. Samples taken from LDEF were used to investigate the quantities of radionuclides produced in LDEF materials and their distribution within the spacecraft[11,12,13,14].

COSMOGENIC NUCLEI IN LOW EARTH ORBIT

The most surprising discovery to date on LDEF was the ^{7}Be that was found imbedded on the windward surfaces of LDEF[1]. This discovery was not made by a planned LDEF experiment but as a result of a test conceived prior to retrieval. It was found that the implanted ^7Be ions implied an atmospheric abundance of ^7Be that far exceeded the production in the ambient atmosphere at the orbital altitude of LDEF. Petty[15] has proposed an explanation for this ^7Be. He proposes that the ^7Be is produced much lower in the atmosphere. Above the turbopause, at about 100 km, the constituents of the atmosphere are collisionally decoupled and gravitational fractionation occurs. Petty proposes that above the turbopause, the ^7Be is in the form of ^7Be atoms which become increasingly abundant at higher altitudes due to gravitational fractionation. He calculates the density of ^7Be at the orbit of LDEF to be about 1/4 of the observed lower limit on the abundance, but this calculation is quite uncertain because it depends on latitude, the altitude of the turbopause, and the upper atmospheric temperature.

A second LDEF mission could follow up on this discovery and test the dependences in Petty's theory as well as more detailed atmospheric models. Also other cosmogenic nuclei from the atmosphere below LDEF could be searched for using carefully planned experiments. Figure 1 shows three concepts for experiments that have been suggested by G. W. Phillips* and the author. These experiments, to be located on the windward side of LDEF, will extend the investigation of ^7Be. In figure 1a, an experiment to investigate the time variations in the ^7Be is depicted. The idea is to collect ^7Be ions on a moving strip of aluminum foil that is exposed through an aperture. The movement of the foil must be started approximately 100 days prior to recovery of LDEF. This will require the second LDEF mission to have a command receiver. The foil will be moved at a rate that gives a time resolution of about 1 day. If the temperature of the upper atmosphere varies or solar flares occur during the last 100 days of the mission, the dependence of the ^7Be on can be examined. To find the latitude dependence of the ^7Be, the experiment depicted in figure 1b is suggested. Here the ^7Be is recorded on an aluminum disk which rotates with the orbital period. This disk should be set in motion during the last 100 days of the mission. Only a small sector of the disk is exposed thorough the triangular opening in the shield, so the latitude dependence of the ^7Be is determined with a resolution of 1/10 of the orbit.

Another factor that can affect the transport of ^7Be up to LDEF's orbit is its charge state. It is quite possible that solar UV photons have ionized the ^7Be atoms to $^7Be^{+1}$ ions. Figure 1c. depicts a concept for an instrument to distinguish the ^7Be ions from ^7Be atoms. The three sections of the instrument allow the effects of no electric field to be compared with that of two electric field levels. The neutral ^7Be atoms will implant to the same areal density in the three sections of the experiment, while $^7Be^{+1}$ implantation will be prevented in the two sections that are covered by retarding potential grids. In the first section, the retarding potential of 2.5V potential is only sufficient to prevent implantation of $^7Be^{+1}$ but will permit the implantation of ^7Be if it is in the form of $^7BeO^{+1}$ ions. In the second section, the 8V retarding potential is sufficient to prevent both $^7Be^{+1}$ and $^7BeO^{+1}$ ions from implanting.

In addition to ^7Be, other cosmogenic ions may also be enhanced at LDEF's orbit. J. C. Gregory * and G. W. Phillips* have suggested that experiments on the second LDEF mission should also look for evidence of ^{10}Be, ^{14}C, and ^3H. Unlike ^7Be, these other ions have long half-lives. The plan is to chemically remove them from witness plates flown on LDEF and identify them by accelerator mass spectrometry.

ENERGETIC HEAVY IONS BELOW THE GEOMAGNETIC CUTOFF

A second discovery on LDEF I is the presence of energetic heavy ions below the geomagnetic cutoff[16,2]. The origin of these ions has not yet been established. One possibility is that some of these observations are due to trapped anomalous cosmic rays[3], but it is unlikely that the Fe group ions observed on LDEF[16] are from the anomalous cosmic ray component. We know that the ionization states of anomalous cosmic rays[17] and solar cosmic rays[18] provide unique information about these components of the space radiation environment. It now seems possible that ionization states will provide a new channel of information on other components of cosmic rays. Below, two experiments are suggested for the second LDEF mission that could extend these investigations.

*Private communication. See footnote list at end of paper.

LDEF I carried the Heavy Ions In Space (HIIS) experiment which discovered stopping Fe group ions in low inclination - low earth orbit[16]. A second HIIS experiment, HIIS II is proposed for the second LDEF mission. This experiment would also comprise two trays on the space facing end of the vehicle. HIIS II would differ from the version flown on the first LDEF mission. It would have a thinner window in the top of each module and would make more use of the CR-39 plastic track detector. All the track detectors would be sealed in an atmosphere of dry air with a much larger ballast volume of air than in the first mission to improve the detector performance (see figure 2). This experiment would once again be entirely passive.

The second experiment to measure stopping heavy ions was suggested by Rudolf Beaujean*. This would be similar to the experiment flown on SPACELAB I[19,20]. It would consist of a fixed detector stack and a rotating one (see figure 3). The rotating stack would rotate in both directions with its position always adjusted to coincide with the local geomagnetic cutoff. This experiment would require power and telemetry. The down-link telemetry would carry housekeeping data on the instrument and its operation. The up-link would be used to update the onboard data base that controls the rotation of the stack to correct for changes in the orbital period as the orbit decays. A 57° orbit is prefered for this experiment and a 9-12 month flight.

ULTRAHEAVY COSMIC RAYS

Figure 4 compares the integral number of galactic cosmic ray iron ions collected above any threshold energy for several past, present, and proposed ultraheavy cosmic ray experiments. The Skylab[21], HEAO[22], and Ariel[23] experiments are completed. The UHCRE[6] and the HIIS[5] are in analysis and the TREK experiment[24] is presently being exposed onboard the MIR Space Station. The HNC experiment[25] was accepted for the reflight of the original LDEF spacecraft. The HNC experiment was well into development when the LDEF re-flight was cancelled following the Challenger accident. Subsequently HNC was accepted to fly on the Spacestation, but due to reductions in the size and capabilities of the Spacestation, this flight has been indefinitely delayed.

Since the HIIS and UHCRE experiments were prepared for the first LDEF mission, a new high resolution phosphate glass detector has been developed[26]. Accelerator tests indicate that this new detector should be capable of individual elemental resolution throughout the periodic table. Its use will make possible detailed measurements of the elemental composition of ultraheavy cosmic rays. These measurements can be used to investigate the origin and evolution of matter in our galaxy and search for evidence of new forms of matter such as superheavy elements and magnetic monopoles. HNC can also be used to test theories of the propagation of cosmic rays in the Galaxy. The scientific objectives of HNC have been repeatedly given high priority by NASA advisory panels (see, for example, NASA's Space Physics Strategy Implementation Study for 1995 - 2010[27]).

Because ultraheavy cosmic rays are rare, an HNC detector on LDEF II should be as large as possible, utilizing all the trays on the sides and space end of LDEF. The size of the data sample can be further increased by a mission of 6 years or more in a 57 degree inclination orbit. Figure 5 shows an LDEF tray filled with a mosaic of stacks of phosphate glass detectors. The detectors are held between silicon separators which allow for differential expansion and protection from shock and vibration. Each tray will be filled to its maximum weight limit with these glass detectors and the tray will be covered with a thermal blanket. There is no need for sealing the detectors in an atmosphere of air as in the case with plastic detectors.

HNC is a simple passive experiment requiring no power or telemetry. It makes minimum demands on the spacecraft. The experiment will rely on passive thermal controls to minimize the temperature excursions of the experiment during flight. Since thermal blankets have proven effective micrometeoroid collectors, HNC would be compatible with a micrometeoroid experiment that used the retrieved thermal blankets for their data source.

COMPOSITION AND ENERGY SPECTRA OF COSMIC RAYS ABOVE 3 TeV/amu

It is thought that the bulk of cosmic rays are accelerated by shock waves from supernovae of various ages. It is recognized, however that these shocks have a limited strength and may be unable to accelerate cosmic rays much above 10 TeV/amu[28]. Indeed, indirect ground-based observations have produced persistent reports of anomalies in the intensity and composition versus total kinetic energy in the energy range of 100 to 10,000 TeV. Above an energy in the range of 10 to 100 TeV/amu, a different mechanism may be responsible for cosmic ray acceleration. Superbubble shocks powered by multiple supernovae[29,30] and a shock associated with the termination of the Galactic wind[30] are among the suggestions for the acceleration mechanism at these high energy cosmic rays.

To investigate the transition region from supernova shock acceleration to the mechanism at higher energies, Y. Takahashi* has proposed to measure the elemental composition and energy spectra of cosmic ray nuclei heavier than Na in the energy range from 3 to 100 TeV/amu. This will be done with a passive calorimeter consisting of plastic track detectors, nuclear emulsions, X-ray films, and lead absorbers. This approach has a long heritage. It has been used successfully for years by the JACEE collaboration to make similar measurements on balloon flights. LDEF will allow a large increase in both exposure time and payload mass allowing the measurements to be carried to higher energies.

Figure 6 shows an LDEF tray containing the calorimeter. The calorimeter can be designed to weigh as little as 180 lbs per tray, but would benefit from more mass per tray. A minimum of 6 trays are needed for a one year mission in any orbit. The calorimeters are completely passive and require no power, telemetry or onboard data recording. The trays of this experiment can be located on the sides or space-facing end of LDEF. Because of their mass, they could be used to establish the desired mass distribution for LDEF II. This experiment is also compatible with space debris sub-experiments utilizing the thermal covers and perhaps solar arrays if the experiment can be kept cool under the solar arrays.

DOSIMETRIC AND SPECTROSCOPIC MEASUREMENTS OF RADIATION

The space radiation environment is known to pose a radiation hazard to men in space. The radiation dose-equivalent comes from many sources. The external radiation environment of the manned spacecraft consists of trapped protons and electrons, cosmic rays and occasionally solar energetic particles. In passing through the walls of the spacecraft these radiations are attenuated and modified by nuclear interactions. Inside the spacecraft the penetrating external components and their fragments are present but their intensity is non-uniform and anisotropic due to the non-uniform shielding provided by the spacecraft. In addition to particles originating outside the spacecraft there are additional radiations that result from the nuclear reactions caused by the external components. These radiations consist of neutrons, protons and heavier fragments of the atoms of the nuclei from which the spacecraft is constructed.

With the dose-equivalent to the crew coming from so many non-uniform and anisotropic components, predicting the exposure in a given mission is a complex problem. To investigate this problem for the planned Spacestation, LDEF I was instrumented with several kinds of radiation detectors. Considerable progress has been made in understanding the relative importance of the various components and the non-uniformities caused by the mass distribution in a spacecraft from the measurement made on LDEF I[9,10,31-38]. These results have shown that detailed spacecraft modeling calculations can generally reproduce the complex pattern of doses and anisotropies observed on LDEF, but more detailed investigations are needed.

Figure 7 shows the proposed locations of four types of advanced passive and active dosimeters on the second LDEF mission that have been suggested by E.V. Benton*. The first of these, the Trackoscope, provides a 4π survey of the anisotropy in protons, galactic cosmic rays and secondary charged particles coming from the spacecraft material. To investigate the real-time distribution of radiation doses around the orbit, an active tissue equivalent proportional counter (TPEC) has been proposed. This unit measures the LET spectrum in real-time and can be used to investigate how this spectrum varies with orbital location. To investigate the importance of secondary neutrons from the spacecraft material and its dependence of shielding, Bonner Spheres will be flown in four locations around the LDEF. Finally, shielded stacks of various passive detectors are proposed to investigate the effects of shielding on the incident radiation from the space environment. These detectors will measure LET spectra, particle fluences, dose and dose-equivalent under various amounts of shielding.

The total weight of the proposed detector packages for this experiment is about 40 Kg, distributed as shown in figure 7. Each location takes only a small fraction of a tray. The active instruments will be battery powered and will record their data onboard. No power or telemetry will be required. A 28° inclination orbit at 450 km is preferred because it's the same as the Spacestation and a mission duration of three years is preferred.

CONCLUSION

A sampling of space radiation experiments have been discussed which show the breadth and richness of the investigations that could be conducted on a second LDEF mission. The experimental concepts discussed here are by no means complete. Many additional concepts have already been proposed and, no doubt, others would emerge if NASA makes the decision to offer flight opportunities on additional LDEF missions. The range of experiments that can be conducted on the LDEF carrier and the number of individual investigations that can be accommodated on each flight make LDEF a cost-effective way to meet the needs of several science and engineering disciplines for access to space.

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FOOTNOTES

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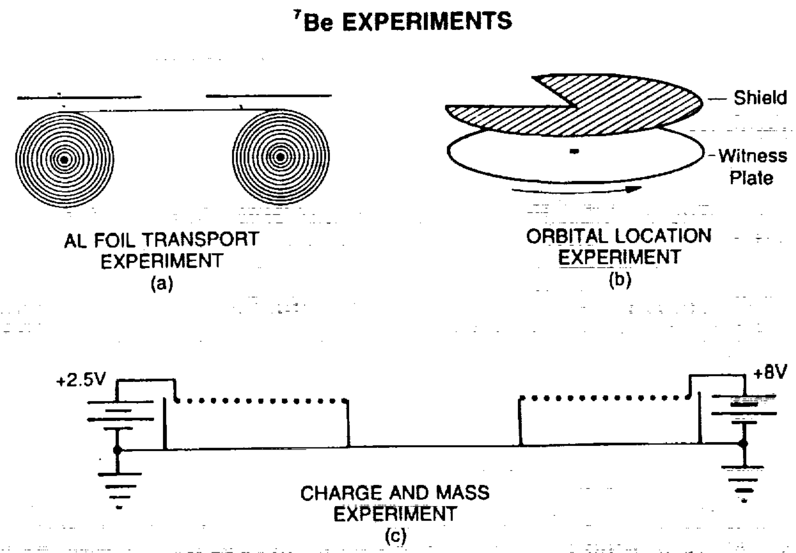

Figure 1: Concepts for further investigations of ^{7}Be in low earth orbit. (a) A device to measure the orbit-averaged ^{7}Be atmospheric density versus time. (b) A device to measure the density of ^{7}Be around the orbit of LDEF II. (c) A device to measure the charge and mass of an ion of ^{7}Be. If the ^{7}Be is charged, it can be repelled from the witness plate by an electric field. $^{7}Be^{+1}$ can be repelled by a 2.5V potential. Should the ^{7}Be be in a chemical form such as $^{7}BeO^{+}$ it can be repelled with an 8V potential.

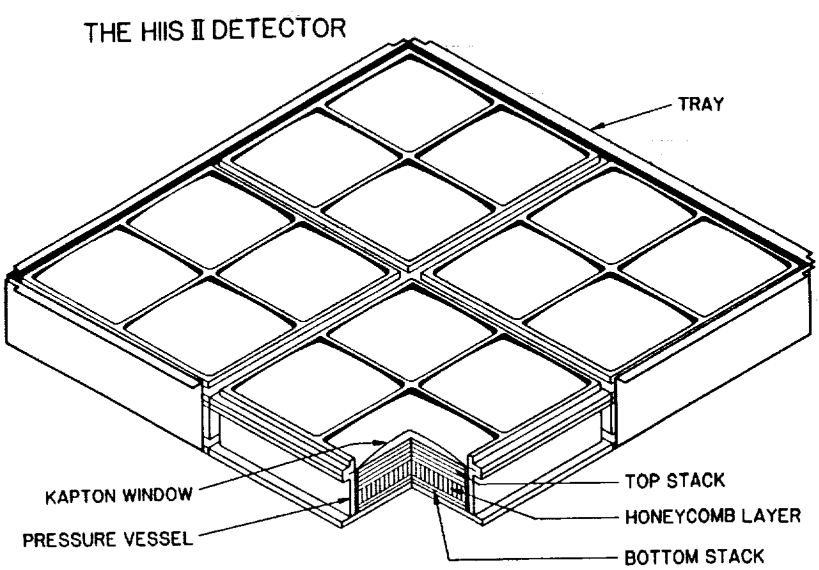

Figure 2: The HIIS II concept. Each tray will contain four track detector modules. Each module will contain two stacks of plastic track detectors. The upper stack will record the particles below the geomagnetic cutoff and will be under a 125 μm kapton window in the lid. The lower stack will be below a lead degrader at the bottom of each module and will record galactic cosmic ray iron group ions that come to rest after passing though the lead. Between the two stacks will be a ventilated honeycomb layer to contain ballast air for the module.

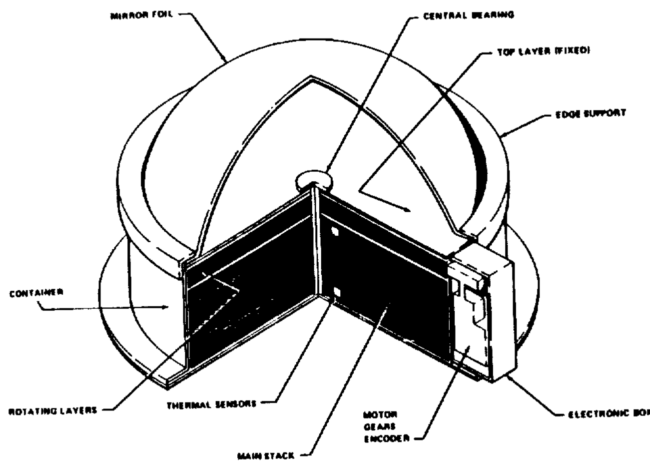

Figure 3: A concept for a rotating detector which records cosmic ray tracks at different geomagnetic cutoffs. The geomagnetic cutoffs at which the cosmic rays were recorded are determined by matching the tracks in the fixed and rotating detector stacks (courtesy of R. Beaujean, Kiel University).

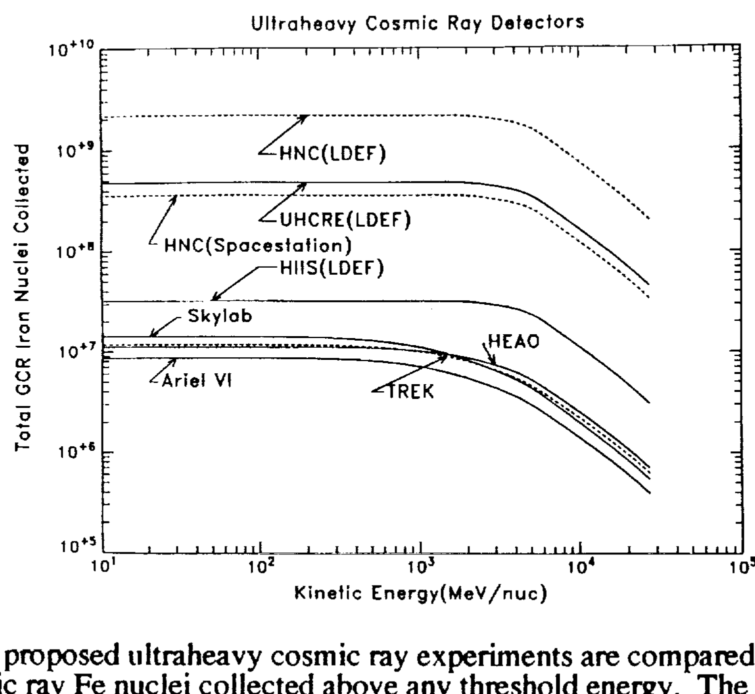

Figure 4: Present and proposed ultraheavy cosmic ray experiments are compared according to the number of cosmic ray Fe nuclei collected above any threshold energy. The Skylab, HEAO, and Ariel VI experiments are complete. The UHCRE and HIIS experiments are in analysis and the TREK experiment is currently collecting data on the MIR spacestation. The HNC experiment has been proposed as the logical next step in the investigation of ultraheavy cosmic rays. First HNC was selected for the re-flight of LDEF, but cancelled following the Challenger accident. It was also selected for Spacestation, but then indefinitely delayed due to the downsizing of Spacestation.

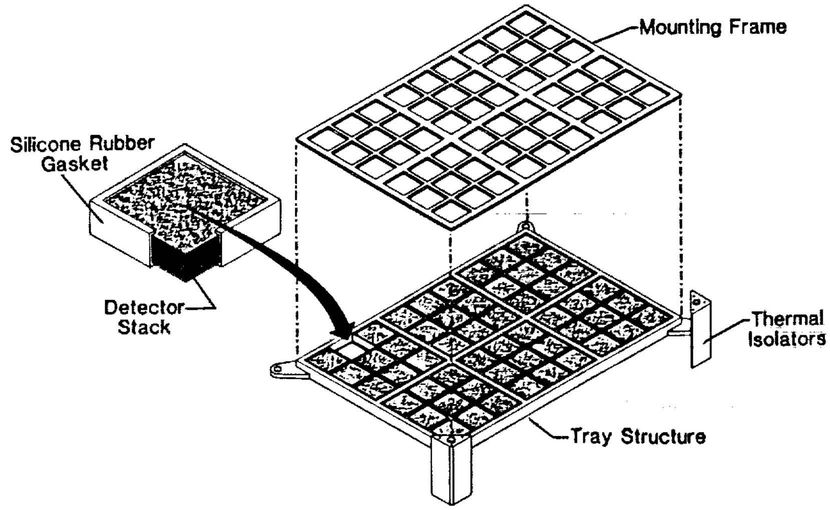

Figure 5: The HNC Detector and Tray Assembly Concept (courtesy of W. Kinard, LDEF Project Office, NASA LaRC).

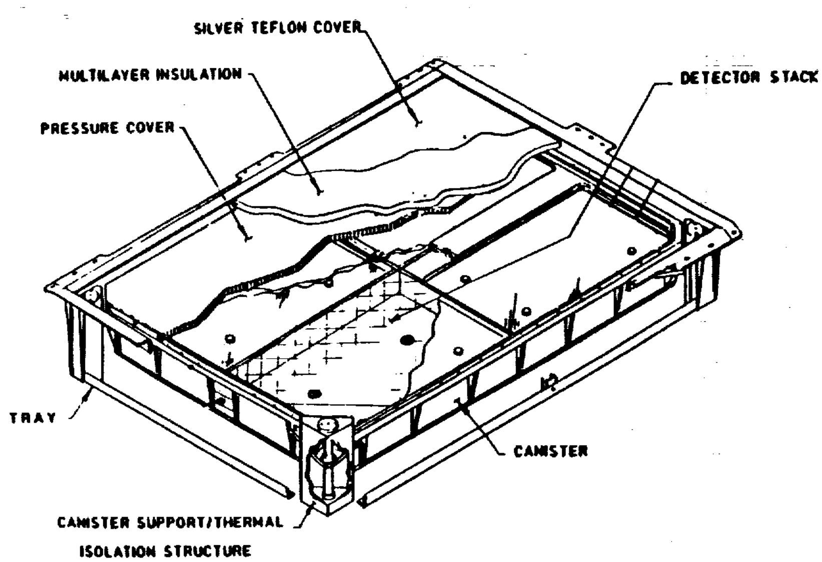

Figure 6: Concept of loading a detector stack unit of the High Energy Composition and Spectra Experiment into an LDEF tray (courtesy of Y. Takahashi, UAH).

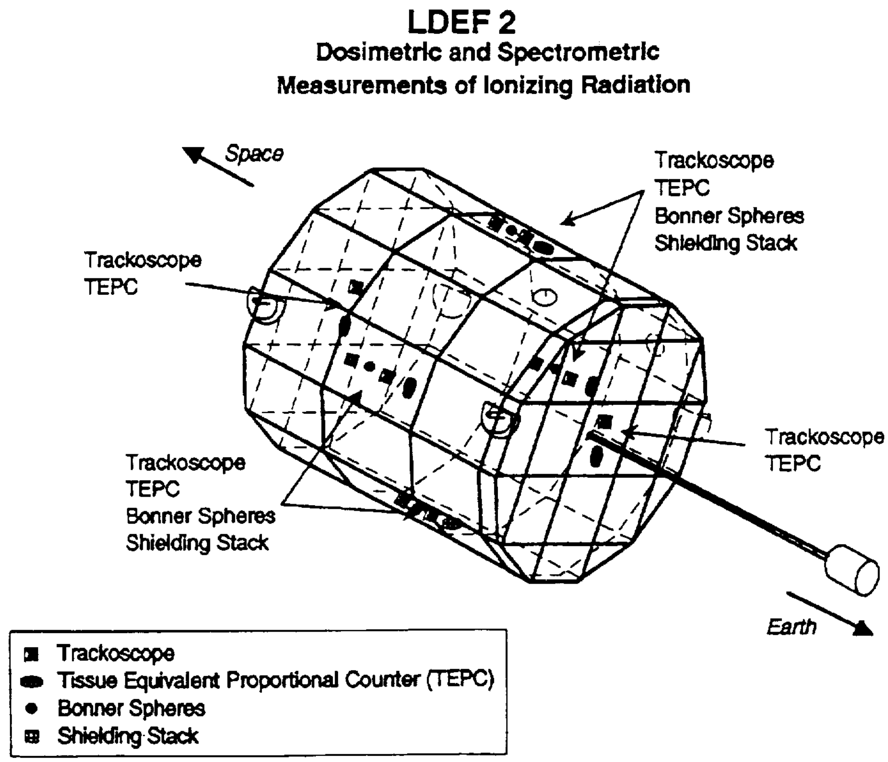

Figure 7: This figure shows the proposed locations of four types of advanced passive dosimeters that could make dosimetric and spectroscopic measurements of ionizing radiation on LDEF II (courtesy of E.V. Benton, U of SF).