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DEFINITION STUDY FOR AN ADVANCED COSMIC RAY EXPERIMENT UTILIZING THE LONG DURATION EXPOSURE FACILITY

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PART I

Technical Plan

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1. Summary of Requirements for Ultraheavy Cosmic Ray Experiment

A. Technical Plan

Flight Requirements:	2 years; 57° inclination; 230 nm (436 km) altitude; near solar minimum (1986).
LDEF Usage:	61 trays around periphery concentrated toward trailing edge (west).
Tray Contents:	4 modules; 0.7 m^2 total active area per tray; thermal blanket; thermal labyrinth mounts; Al honeycomb mechanical support; total tray weight ~100 kg.
Module Contents:	Interleaved CR-39, Lexan and thin copper sheets + 1 event-thermometer, canned in thin metal cannister sealed with ~0.2 atm dry O_2.
Event Thermometer:	Stiffened CR-39 sheet that slides via bimetal strips relative to fixed CR-39 sheet so that stack temperature can be read out for each event. Metal cannister will be collapsed at launch and landing, capturing sliding assembly to prevent damage.
Plastic Detectors:	CR-39 and Lexan will be manufactured to our specifications.
Sheet Copper:	Will be rolled to our specifications. Thickness for important events will be determined by accurate punching and weighing after flight.

From our study we conclude that an experiment with the specifications summarized above and presented in detail in the body of this report will provide ~30 times more events and much better charge resolution than will be obtained in the Irish experiment scheduled for the first LDEF, and it will provide ~10^2 times more events and at least twice as good charge resolution as attained in the HEAO-3 ultraheavy cosmic ray experiment. Our accelerator simulation of trapped radiation and our calculations show that for an LDEF reflight at an altitude no higher than 225 nm the radiation background will be insignificant. Engineering studies of a prototype LDEF tray will include thermal and mechanical tests of detectors and the event thermometer.

B. Management Plan

NASA Headquarters will determine the mechanism for selecting the Principal Investigator and Guest Investigators. The Principal Investigator will be responsible for constructing one prototype module containing a stack of interleaved copper and plastic sheets and an event thermometer, and for subjecting it to thermal tests. The Principal Investigator will be responsible for constructing the experiment and processing the detectors under uniform conditions when the material is returned from space. The Guest Investigators will equip their laboratories to assist in data analysis.

2. Introduction

Accurate measurements of the composition of the ultraheavy cosmic rays may hold the key to our understanding of explosive nucleosynthesis. Determination of the relative abundances of elements at the r-process (synthesis by rapid neutron capture) peak at platinum, at the s-process (synthesis by slow neutron capture) peak at lead, at the actinide peak at uranium, and among the transuranic elements would tell us more about the origin and subsequent history of cosmic rays than any experiment yet done. A good measurement of the abundance of U and Th would determine the time since nucleosynthesis and thus answer the question as to whether the cosmic rays are swept-up interstellar material or material synthesized in exploding stars and promptly ejected and accelerated. Unfortunately, the abundance of the actinide elements appears to be so low that an instrument with a collecting power of ~ 100 m^2 ster flown for two years in a high-inclination orbit (57°) at solar minimum will be required if we want to collect at least 30 actinide nuclei above 200 MeV/amu, assuming no enrichment above present-day solar abundances (i.e., 4.6 x 10^9 years old) at the cosmic ray source.

The Long Duration Exposure Facility (LDEF) provides a convenient, low-cost platform upon which experiments of this large magnitude can be mounted and deployed. Using 61 LDEF peripheral trays, a total geometry factor approaching 100 m^2 ster can be achieved. With a maximum tray weight of 107 kg, detector thicknesses up to ~9 g/cm^2 can be used. The ability to carry thick detectors is a distinct advantage: for a given detector, the resolution increases roughly as the square root of the thickness up to the point at which nuclear interactions become significant. The slowing of nuclei in matter can be used to decouple the energy from the charge. The greater the thickness, the easier this process becomes. By interleaving detector elements with sheets of a heavy material such as copper or lead, the required slowing can be achieved without sacrificing particles to nuclear interactions.

A potential problem with the LDEF is that it does not keep a fixed orientation toward the sun, and therefore the thermal protection that can be achieved with passive coatings is poor, becoming increasingly worse with increasing orbital inclination. Since the response of CR-39 and Lexan has been shown to depend on temperature[1] (as do most detectors) some means must be found to control the detector temperature or to record the temperature for each event by means of an "event thermometer." Since only limited power is available on LDEF, passive detectors and thermal protection systems are the logical choice for a long mission.

In our study we considered the possibility of using a newly developed Cerenkov ring-imaging system to determine, with high precision, both particle charge and velocity in a single detector element. A readout scheme was developed which used negligible power. While such a system showed great promise, further development is needed, and we concluded that the new CR-39 passive track detector, supplemented by Lexan and employing an "event thermometer," would be the cheapest and best approach for an experiment on LDEF.

3. Justification for Dedicating a Second LDEF Mission Primarily to Ultraheavy Cosmic Rays

Figure 1 shows preliminary results from two recent ultraheavy cosmic ray experiments using electronic detectors on Ariel-VI and HEAO-3. Since these data were obtained, some further progress has been made: even-Z peaks appear to be detected in a selected subset of HEAO-3 data up to $Z = 56$, making possible estimates of relative abundances of the even-Z elements, but not of the odd-Z elements. Only two to three actinide nuclei ($Z \gtrsim 90$) were seen in the two experiments, whereas 10 to 20 should have been detected if the ultraheavy cosmic rays were dominated by products of r-process nucleosynthesis, as would be expected according to some models of supernova origin of cosmic rays. These data suggest a source consisting of old interstellar gas with the very low ratio of actinides to lead- and platinum-peak elements ($Z = 76$ to 83) characteristic of the solar system or possibly even lower, if the interstellar gas has a lower r-process to s-process ratio than the solar system. (This has recently been suggested by D. Schramm.)

Table 1 makes it clear why a new ultraheavy cosmic ray experiment is needed and shows that an LDEF reflight can provide the necessary improvement in collecting power. Even before and during the Skylab experiment (the first entry in the table), a series of balloon-borne experiments using Lexan and nuclear emulsions attained a total collecting power comparable to that on Skylab and reported the detection of more than a dozen actinide nuclei ($Z \gtrsim 90$), but with uncertain resolution. The discovery by Thompson et al.[1] that the response of a plastic detector depends on the temperature of the material at

Table I. Past and Future Ultraheavy Cosmic Ray Experiments

Mission	Institution	Year launched	Duration	Nominal geom. factor (m^2 sr)	No. of iron nuclei passing through detector*	No. expected if propagated solar system abundances†		
						Pt	Bi	$Z \gtrsim 90$
Skylab	UCB	1973	250d	2.6	2×10^7	14	0.4	0.6
Ariel-VI	Bristol	1979	180d	2	1.5×10^7	10	0.3	0.5
HEAO-3	several	1979	20 mo.	6	3.3×10^7	23	0.7	1
LDEF-I	Dublin	1984?	13 mo.	20	3.7×10^7	26	0.9	1.1
LDEF-II	UCB?	1986?	2 y	10^2	1.3×10^9	1000	27	40

*Because of differences in solar activity, orbital inclination, detector orientation, shadowing by the Earth, and mission duration, this number does not scale exactly with geometry factor.

†We calculated fluxes of iron nuclei for various orbits and detector orientations (see Fig. 2 for examples relevant to LDEF-I and II), and used the ratios of Pt, Bi, and $Z \gtrsim 90$ to Fe obtained by Tsao et al.,[2] which were solar system values propagated through space and corrected for first ionization potential.

the time of the irradiation explains why the intrinsically high resolution of plastic detectors is degraded when the exposure extends over a day-night cycle on a balloon and points the way to achieving much higher resolution by minimizing temperature variations in new experiments.

The temperature variations within the Skylab, where the Lexan stack was located, were small enough not to degrade the resolution, but the stack was too thin to permit really good charge resolution. After a 250 day exposure of the 1.2 m^2 Lexan stack, seven actinide nuclei appeared to have been detected, whereas Ariel-VI and HEAO-3 detectors, with somewhat greater collecting power, reported only 2 and 1 actinide event respectively. Five of the seven events seen in the Lexan had energies less than 450 MeV/N, whereas the electronic detectors on Ariel-VI and HEAO-3 studied only nuclei at higher energies. We do not know whether the higher actinide collection rate on Skylab was a statistical fluctuation, an incorrect charge assignment due to poor resolution, or an indication of an excess of actinide events at energies below the thresholds of the other two instruments.

If we accept the Ariel and HEAO results, then the ratio of actinides to lighter elements such as iron or the platinum-lead group ($74 \lesssim Z \lesssim 83$) may be as low as it was in the material from which the solar system formed. The expected number of events, listed in the last three columns of Table 1, were calculated assuming a source with solar system abundances, propagated through a mean thickness of 5.5 g/cm^2 of interstellar medium, with corrections for first ionization potential, and calculating fractional accessibility to a detector with a particular orientation and orbital inclination. Figure 2 shows the results of calculations of numbers of actinide nuclei ($Z \gtrsim 90$) as a function of energy for inclinations of 28.5° and 57°. It is obvious from the curves that the Irish detector, even if its area were as large as 100 m^2 sr and its exposure were two years, would see no particles with energy below ~1 GeV/amu and would see far fewer particles than in a 57° orbit. If the reason for the larger number of actinide nuclei seen on Skylab than on Ariel-6 and HEAO-3 is that there is an excess at energies below 500 MeV/amu, then a 57° orbit offers an opportunity to see this excess.

With sufficiently good statistics and charge resolution, one could look for specific tracers of recent r-process synthesis such as $_{96}$Cm, $_{94}$Pu, and $_{93}$Np, as well as for enrichments in Bi due to radioactive decay of transuranic r-process nuclides. Table 2 shows the number of various actinide nuclei expected in a 100 m^2 ster detector exposed two years at solar minimum in a 57° orbit, assuming several different source compositions. The first row, assuming the present solar system composition with radioactive nuclides having decayed for 4.6 x 10^9 years, gives a high Th/U ratio and no transuranic events. The last row is based on the rather extreme assumption of pure r-process source material after 10^7 years of radioactive decay. The HEAO-3 and Ariel-6 data appear to rule out such a source. Rows 2, 3, and 4 assume a 10% admixture of r-process material and 90% material of solar system composition at 10^6, 10^7, and 10^8 years after the r-process event. None of the first four scenarios can be ruled out by existing data. With a two-year exposure of a 100 m^2 ster detector one could detect an r-process contamination at about the 10% level. If the fraction of r-process material were appreciably greater than 10% one could even estimate the time of the r-process addition from the relative numbers of Np, Pu, and Cm, and set a useful limit on the flux of exotic, highly ionizing particles such as superheavy elements.

4. Recommendation of Cosmic Ray Program Working Group

The Cosmic Ray Program Working Group, chartered by NASA to recommend a strategy for cosmic ray research in the coming decade, expects to complete

Table 2. Examples of Possible Actinide Element Event Rates (per 100 m^2 ster per 2 years at solar minimum in a 57° orbit)

	Th	U	Np	Pu	Cm
4.6 Gy-old solar system abundances (SS)	21	5	0	0	0
90% SS + 10% 10^6 y-old r-process material	22	11	3	2.5	3
90% SS + 10% 10^7 y-old r-process material	22	11	0.2	2.9	1.8
90% SS + 10% 10^8 y-old r-process material	24	11	0	1	0
100% 10^7 y-old r-process material	7	83	2	29	18

[All numbers are highly uncertain and are meant mainly to show that relative abundances have useful diagnostic value.]

its study in the spring of this year. This Working Group ranks the ultraheavy cosmic rays as one of the major areas of cosmic ray astrophysics to be studied by new space observatories in the 1980's. In view of NASA's fiscal constraints and the expectation of very limited new opportunities for at least a decade, the Working Group has decided to recommend a reflight of the LDEF with most of the trays outfitted with plastic detectors for the mid-1980's, followed by another ultraheavy cosmic ray experiment to go on a Space Platform in the early 1990's. An LDEF reflight, despite the less than optimal configuration of plastic detectors, would be so much cheaper than a free-flying platform of optimal, planar configuration that the choice seemed irresistible. Estimates of the cost of designing and constructing a planar platform ranged from many tens of millions of dollars upward, whereas the cost of refurbishing the existing LDEF after retrieving it was estimated at only a few million dollars. An earlier letter (June 2, 1981) stating the view of the Working Group is attached.

5. Performance of CR-39

The discovery by our group[3] of the remarkable track-etch properties of the polymer of allyl diglycol carbonate (CR-39) has led to significant advances in particle detection technology. Perhaps the most important of these has been the demonstration[4] that the charge resolution of CR-39 exceeds that of any other particle detector of equivalent thickness, including silicon semiconductor detectors. This is illustrated in Fig. 3 in which we plot the average minor axis of cones produced by particles emerging from a block of polyethylene which was irradiated by 1.86 GeV/amu ^{56}Fe nuclei from the LBL Bevalac. Four cones were used to calculate the average. The separation of the iron peak from the particles with small charge which were produced by

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Reply to Attn of: Cosmic Ray Program Working Group

Mr. Jesse W. Moore/SM-8
NASA Headquarters
Washington DC 20546

Subject: Reflight of the Long Duration Exposure Facility (LDEF) for Space Science Studies

At our May 28 meeting of the Cosmic Ray Program Working Group at the Goddard Space Flight Center, we learned that the Office of Space Science will soon be asked to consider supporting a reflight of the LDEF for space science studies.

The LDEF, without significant modification, has the capability of carrying a large-area array of passive detectors designed to measure the elemental abundance of ultraheavy cosmic rays. Such an experiment, with 40 to 50 m^2 (providing more than an order of magnitude greater collecting power than the HEAO-3 heavy nuclei experiment) could be a logical next step in the study of these very rare nuclei. It would provide good statistics on uranium and other actinide elements, even if they are not enriched above their very low solar abundances. Such a study is among the important goals of cosmic ray research for the next decade.

Although the deliberations of our Working Group will not be completed for at least 6 months and detailed studies of the response of these plastics to cosmic ray nuclei are still in progress, an LDEF reflight with such an experiment already appears to be a promising approach to this study. It is particularly attractive because of its relatively low cost and relatively early (1985) launch opportunity.

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spallation of iron in the polyethylene is apparent. The charge standard deviation at iron is $\sigma_z = 0.12e$, which is a factor of 2 smaller than was observed with one cone. This suggests that the fluctuations of successive cones for a given particle are uncorrelated and implies the possibility of extraordinarily small errors in charge assignments for averages taken over many cones. For example, with the use of 16 cones the above charge resolution would be expected to be 0.06e. Of course, this would be most easily realizable in an accelerator exposure for which environmental and irradiation conditions can be controlled and stabilized.

For experiments in space, for which large variations of arrival angles and environmental conditions are possible, the practically realizable resolution would be expected to be poorer than that achieved in accelerator tests. We have investigated the sensitivity to these effects at the Bevalac, in a balloon flight, and with radioactive sources. In Fig. 4 we show the results of our study at the Bevalac of the dependence of response on zenith angle. The apparent value of reduced track etch rate is plotted for four zenith angles for 600 MeV/amu ^{56}Fe nuclei. For comparison we show the signal of Mn at 600 MeV/amu on the same figure. It can be seen that the angular effects are negligible in comparison to a charge unit ($\sigma < 0.08e$). In Fig. 5 we show the results of a balloon flight in which we determined the charge of 103 cosmic ray particles with energy from 400 to 800 MeV/amu at the top of the detector. Charge assignment was accomplished by determining the mean minor axis of three cones above a slab of lead 1 cm thick and the mean minor axis of two cones below the lead. The CR-39 detectors were enclosed in sealed bags which provided a 1 atm air environment for the entire 36 hour duration of the balloon flight. Passive thermal control limited peak to peak temperature excursions of -8° C to 16° C during the flight. The detectors which we utilized contained the additive DOP, which was discovered by G. Tarlé[4] to enable the CR-39 to be etched for long times without becoming translucent. This was essential in order to measure zenith angles accurately enough to apply the angular corrections required by track geometry effects. The CR-39 which was used for the accelerator tests described above also contained DOP. From Fig. 5 it can be seen that the standard deviation of the iron peak is ~0.25e, significantly worse than one would expect on the basis of the Bevalac tests. However, this is easily understood when one considers temperature effects. In Fig. 6, we show the sensitivity of reduced etch rate for 6.1 MeV alpha-particles from ^{252}Cf as a function of temperature. Since the reduced etch rate for 6.1 MeV alpha-particles is comparable to that for relativistic iron particles, we expect the same temperature dependence for our balloon flight results. By considering the measured temperature variation during the balloon flight (lower right of Fig. 6), we estimate a charge standard deviation of 0.22e due to temperature effects. By tabulating fluctuations from the mean minor axis of the minor axes of the three cones measured above the lead, we have determined the intrinsic resolution of the balloon flight results. This is the resolution one would expect if all particles had the same zenith angle and if they penetrated the detector at the same time. The results are shown in Fig. 7. They indicate that with three cones, the intrinsic resolution is σ_z = 0.12e, slightly better than would have been anticipated from the Bevalac tests (this is probably due to the longer etch time and/or to the lower average particle energy for the balloon flight). By adding this in quadrature to the temperature fluctuations, we calculate a net standard deviation of 0.25e, as was in fact observed.

All of the above results were obtained from measurements of minor axes of track mouths. There are a number of reasons to expect that such measurements are superior to those of cone lengths, such as have been used predominantly in the past. This is particularly true for CR-39 which contains DOP insofar as the track mouths are virtually precise mathematical ellipses with structural deformities being smaller than a fraction of a micron. Some of the reasons for the advantage of track mouth over cone length measurements are listed below:

1) It is much easier to obtain high-quality optical measurements of track mouth parameters than of track depth; one does not need to focus through plastic material and the contrast associated with track mouths is excellent; with care one can obtain reproducible measurements of minor axes in air to ~0.1 micron, whereas depth measurements can be done to no better than ~0.5 micron even with oil immersion objectives having the highest available numerical apertures.

2) The ability to perform high-quality measurements in air speeds up enormously the measuring process, as anyone who has ever used oil immersion objectives can attest.

3) Since one need only focus on the surface of the plastic detector for minor axis measurements, automated scanning and measuring techniques which are free from human bias are easily implemented; in fact, recently developed measuring systems intended for use in the semiconductor industry are ideal for minor axis measurements.

4) Track depth measurements are increasingly difficult to make at zenith angles approaching zero; systematic angular-dependent factors associated with the interpretation of optical images are quite severe; these are virtually

non-existent for minor axis measurements.

5) Aside from this angular dependence of optical nature, the possibility of angular dependence due to a depth dependence of chemical reactivity is much greater for cone length measurements than for minor axis measurements. This is due to the fact that minor axis measurements sample a thickness of plastic less than the amount of material removed by general etching.[4] Cone length measurements sample a much greater range of material depth with a concomitant increase of possible variability of reactivity.

6) The conical pits with large cone angles suitable for minor axis measurements are much less subject to fluctuations in etching kinetics than are the long, narrow cones for which depth measurements are required.

Of course, the tracks of ultraheavy nuclei we intend to study on the second LDEF cannot be processed and measured the same way as has been done for the iron group nuclei. A platinum or lead nucleus would, in CR-39, result in a very long, thin cone whose mouth diameter would be a very insensitive measure of track etch rate. However, there are ways of decreasing the sensitivity of CR-39 to a sufficient extent that minor axis measurements can be used. The most suitable method is the alcoholic etch, where ethanol or methanol is added to the standard etching solution of NaOH.[5] One such etchant which has been used[6] contained 15 parts by weight of NaOH, 31.6 parts of methanol and 57.4 parts of water. The effective threshold of CR-39 with this solution was raised from $Z/\beta \sim 6$ to $Z/\beta \sim 30$. The track quality for alcoholic etches has been shown to be as good as for normal etches[6] and sensitivity can be reduced even more than described above.[6] One problem associated with alcoholic etches is that of volatility of the alcohol component. As etching proceeds, both water and alcohol evaporate and unless they are replenished in the proper proportion, the etch rate will vary with time. However, this problem can be easily overcome with a well-designed, sealed etch tank in which the alcohol and water are refluxed into the etch bath. A small, well-made tank would be adequate even for an experiment as large as the second LDEF, using the following procedure. Most of the etching would be done on the Lexan and some of the CR-39 sheets in a standard, aqueous 6.25 N NaOH bath and these sheets would be used to locate the relatively small number of tracks of the interesting, very heavily charged nuclei. Once located, these events could be cut out of the remaining CR-39 sheets, which would be subjected to an alcoholic etch. The resulting tracks could then be analyzed in the same manner as the previously described iron tracks. In addition to permitting the use of minor axis measurements, the alcoholic etch would greatly reduce the density of background tracks caused by protons trapped in the radiation belts. This would improve resolution by cleaning up the track geometry.

The optimal alcoholic etch conditions will be determined by us in the coming months, when the upgraded Bevalac is completed. We will then be able to expose CR-39 and Lexan to nuclei as heavy as lead and uranium and will calibrate detector response and determine the effects of temperature sensitivity and radiation background as well as optimize alcoholic etch conditions. It is important to study these effects with the same types of ions we intend to study on the LDEF. For example, the temperature dependence displayed in Fig. 6 is in the opposite sense from that determined by studies with low-energy ^{40}Ar and ^{56}Fe ions reported elsewhere.[1] This is probably due to a dependence of repair kinetics on damage density in the latent track. Furthermore, we have observed in our balloon data and in accelerator tests that the CR-39 response cannot be characterized by a simple dependence on the ratio

Z/β. Thus, it is not possible to predict accurately the behavior of CR-39 in response to relativistic lead and uranium nuclei. However, beams of these particles will be available in a few months and these questions can be answered at that time.

6. Performance of Lexan

The Irish experiment on LDEF-I consists of stacks 5.6 g/cm^2 thick containing interleaved lead (6 sheets), Lexan (65 sheets), and a small amount (4 sheets) of CR-39. The thickness of the pure Lexan stack on Skylab was only 1.0 g/cm^2. The fractional standard deviation in charge for the Skylab experiment was typically $\sigma_z/Z \simeq 3\%$. Using the same method of analysis (etched cone length measurements) but increasing the stack thickness to 5.6 g/cm^2, the Irish group should be able to reduce the fractional error to less than 1% for high-velocity ultraheavy nuclei.

As we pointed out in the previous section, the etch pit diameter method has several advantages over the etch pit length method and may enable us, with the 8.94 g/cm^2 stacks to be discussed in section 7, to be able to resolve individual elements among the ultraheavy cosmic rays, using Lexan alone. For $\beta \sim 1$, the minimum detectable charge is $Z \simeq 60$ at vertical incidence. Elements in the platinum, lead, and actinide region can be studied in Lexan over a wide range of zenith angles and at all velocities.

Experiments at the LBL Bevalac involving relativistic beams up to uranium are approved for summer, 1982. We will thus be able to compare the charge resolution of Lexan and CR-39 directly. Based on the proven resolution of CR-39, our strategy is likely to be to use Lexan mainly for rapid location of the actinides via our ammonia technique for finding etched-through holes, and to rely mainly on CR-39, probably with an alcoholic etch, for charge identification. If the Bevalac experiments show convincingly that Lexan, with an etchpit diameter technique, is comparable in quality to CR-39, then we would plan to use both plastics to study the heaviest nuclei and CR-39 to study those below the Lexan threshold of $Z/\beta \simeq 60$.

7. Detector Configuration

In order to achieve the ~100 m^2 ster collecting power required for a definitive ultraheavy cosmic ray study, at least 61 LDEF trays will be required. Each tray will consist of four stack cannisters mounted in an aluminum honeycomb mechanical support structure. This structure will be thermally decoupled from the LDEF tray and exterior and interior panels by means of thermal labyrinth mounts (TLM's) and a one-inch-thick multi-layered insulating blanket (MLI) consisting of alternating layers of aluminized mylar and bridal veil (see Fig. 8). Each stack cannister will contain a main detector stack and a sliding "event thermometer" all sealed in 0.2 atm of dry oxygen. In orbit the cannisters will inflate to fill the support structure and the event thermometer will be free to move. The 0.2 atm of O_2 will simulate the ambient laboratory environment. The total face area of each of the four detector stacks will be 0.174 m^2, resulting in a geometry factor of 1.64 m^2 ster per tray for particles entering at zenith angles between 0 and 60°. The total collecting power for 61 peripheral trays will thus be 100 m^2 ster. Because of the east-west effect (a lower geomagnetic cutoff for positively charged particles arriving from the west), tray positions on the trailing edge (west) are preferred to those on the leading edge (see Fig. 2). Trays on the top of LDEF will collect more particles per unit area but the total area per tray is significantly smaller than for the side trays.

The main stack, outlined in Table II, contains alternating layers of

Table 2. Main Stack Configuration (4 per tray)

Material	Thickness	g/cm^2	Nuclear Interaction Mean Free Paths ^{238}U	Weight of $0.174\ m^2$ Panel (kg)	
Lexan	2–250 μm	0.060	0.013	0.104	repeated 11 times
est. O_2 gaps	65 μm	-			
CR-39	3–600 μm	0.238	0.052	0.414	
est. O_2 gaps	100 μm	-			
Lexan	2–250 μm	0.060	0.013	0.104	
est. O_2 gaps	65 μm	-			
Shim Copper	559 μm	0.500	0.025	0.870	repeated 10 times
est. O_2 gaps	25 μm	-			
TOTALS	3.37 cm	8.938	1.1	15.5 (38.3 lbs)	

shim copper, Lexan and CR-39 plastic track detectors. The total thickness of the main stack is 8.94 g/cm^2 (8.36 g/cm^2 CR-39 equivalent). Calculations show that $\gtrsim$8 g/cm^2 of matter is required to provide sufficient slowing to preserve a charge resolution (at fixed velocity) of $\sigma = 0.25$ charge units for actinide nuclei with energies of up to 4 GeV/amu. With a thinner stack, adjacent high-energy actinide nuclei having the same ratio of charge/velocity, Z/β, would not have a sufficiently different value of Z/β at the bottom of the stack to permit accurate charge measurements. A stack 8 g/cm^2 thick made entirely of plastic track detectors would, because the large fraction of hydrogen present, cause too many nuclear interactions for actinide nuclei passing through it. By interleaving the stack with sheets of a material of high atomic mass, the required slowing can be achieved with many fewer nuclear interactions. Copper, rather than lead, was chosen for these absorbers because it has the high thermal conductivity needed to maintain a uniform stack temperature and an acceptably long nuclear interaction mean free path for actinide nuclei, and because errors due to multiple Coulomb scattering are acceptably small. Lead has a longer nuclear interaction mean free path, but has a much lower thermal conductivity and twice the errors due to multiple Coulomb scattering for a given thickness in g/cm^2. Stainless steel shims would be cheaper, but steel is a very poor thermal conductor. The copper sheets will be rolled to a thickness of 559 ± 5 μm. For certain critical events, the portions of copper along the particle trajectories can be punched and weighed after flight to determine an accurate local thickness. There will be ten copper sheets in each stack separating eleven track detector modules, each consisting of three 600-μm CR-39 sheets separated from the copper on either side by two 125-μm Lexan sheets (see Fig. 9). The CR-39 will be used for the high-resolution studies of the ultraheavy charge composition. Three modes of analysis will be used, depending on the particle energy. Below ~1 GeV/amu, actinide nuclei will stop in the stack and measurements of multiple etch rate versus residual range will be used to determine particle charge. For particles which stop in the copper sheets and for particles with energies between ~1 GeV/amu and 4 GeV/amu, multiple etch rate measurements versus slowing will be used. Above 4 GeV/amu, the charge resolution may degrade slightly but measurements capable of distinguishing U from Th and Pt from Pb can easily be made. The Lexan sheets perform several functions: 1) They can be etched for a sufficient time so that ammonia scanning for cylinders will rapidly sieve out the particles of highest charge for immediate study in the CR-39; 2) they provide a second set of detectors with a different response which can be used to confirm the charge assignment of the CR-39; and 3) they separate the CR-39 sheets from the copper which would, by virtue of a few parts per billion contamination with radioactive impurities, "litter" the CR-39 with alpha-decay tracks. The Lexan is insensitive to the alpha-particles produced in such decays and contains a negligible fraction of radioactive contaminants.

8. Event Thermometer and Thermal Protection

We emphasized earlier that in a long space exposure, temperature variations of the plastic detectors would normally result in a degradation of the superb resolution achieved under the constant temperature of the Bevalac experiment. This can be seen most clearly in the balloon flight results, where a temperature variation of $\sigma = \pm 7°$ C resulted in an irreducible resolution of $\sigma = 0.22$ charge units, whereas in the absence of thermal fluctuations, the resolution would have been $\sigma = 0.12$ charge units for three cones. At a given velocity, adjacent actinide elements are separated by a smaller difference in etch rate than iron group elements, and therefore thermal protection becomes even more important for the LDEF experiment where elements ranging from the iron group all the way up to the actinides will be studied. A proper evaluation of the effect of temperature on the response of track detectors to actinide nuclei will have to await the completion of the Bevalac's new ultraheavy beam facility. Until then, it is possible to make an educated guess as to the degree of thermal protection required, based on results using low-energy Ar and Fe ions with ionization rates comparable to those of relativistic actinide nuclei. Assuming that the response of the plastic to actinides has the same dependence on the ratio charge/velocity that it has for ions of lower charge, we estimate that to achieve an irreducible charge resolution of $\sigma = 0.25$ charge units at uranium would require that the stack temperature for each event be known to ±1° C at 30° C or ±2° C at -30° C. It is possible to maintain temperatures of equipment on large space structures constant to this accuracy with passive thermal systems, provided the spacecraft can remain at a fixed orientation to the sun. The LDEF is a gravity-gradient-stabilized satellite which, in a 57° inclination orbit, will have β angles (angle between the direction of solar irradiation and the orbital plane) between 0° and 90°. Based on the results of thermal modelling for the first LDEF ($0 < \beta < 52°$) one might expect the side structures of the second LDEF to range in temperature from -23° C to 80° C (the upper limit for the first LDEF has been raised from 65° to 85° to compensate for the increased range of β angles for the second LDEF). Correspondingly, based on the first LDEF calculations, the internal average temperature for the second LDEF would range from -12° C to 65° C. Without thermal protection, the gradients in temperature across the second LDEF might, at worst, be as high as 100° C, whereas temperature variation during an orbit might be as high as ±45° C. Independent thermal analysis by Stan Ollendorf at Goddard Space Flight Center has shown that by insulating the LDEF sides and space-end and by painting the earth-end black, the temperature variation can be reduced to ±19° C at an average temperature of 1° C. The cost of this modification was estimated by Ollendorf to be $100 K.

Reduction of instantaneous temperature gradients across the detector stacks to less than ±1° C can be achieved through careful design of the detector stack and mounting. One requirement is that the stack be isothermal to within 1° C at any given time. The thermal time constant for each module should therefore be reasonably short compared to the orbital period of 90 min. and the heat input to the stack through the thermal mounting and protection system must be insufficient to raise the stack temperature by more than 1° C in one half orbit. The copper sheets interleaved between the plastic detectors (see Fig. 9) conduct heat to the interior of the stack so that the center responds to external changes in temperature in the same manner as the edges. For the stack configuration outlines in Table 2 including estimated O_2 gaps, the thermal conductivity is only $K_{\perp} = 0.029$ BTU ft/ft^2 hr °F for series conduction in the direction perpendicular to the stack face, and is as high as $K_{\parallel} = 36$ BTU ft/ft^2 hr °F for the parallel conduction from the edges. The improvement of a factor of ~10^3 for the parallel conduction is due to the presence of the copper sheets. The composite density, ρ, and specific heat, C, of the entire main stack are 146 lb/ft^3 and 0.125 BTU/lb °F respectively. The thermal time constant for conduction to the interior is roughly given by $\tau = \rho C(L/2)^2/K$ where L is the linear size of the stack in the direction of heat flow. The response time for the center of the stack will actually be less than τ for the rectangular geometry. For perpendicular conduction through the stack $\tau \approx 130$ min but is only 15 min for parallel conduction. A similar analysis shows that $\tau < 15$ sec for perpendicular conduction from the copper sheets to the center of each group of Lexan and CR-39 detectors. The stack will therefore have a uniform temperature that will follow that of the aluminum pressure housing surrounding it (see Fig. 8).

Short-term temperature variations are minimized by thermal isolation (conduction and radiation). Thermal Insulating Systems (NASA SP-5027) contains quantitative data on Multilayer Insulation (MLI). Typical equivalent conductivities for one-inch-thick MLI are the order of 10^{-3} BTU ft/hr ft^2 °F. This is so small that such a blanket surrounding the pressure housing (see Fig. 8) reduces radiative heat transfer to the point that only conduction through the mounts need be considered. Thermal mounting within the LDEF tray will be achieved using thermal labyrinth mounts (TLM's). A more detailed mounting design is required before accurate calculations are possible. However, we can estimate the thermal conductance of the required mounts using experience from Kinsey Anderson's experiments on the ISEE-A,B & C satellites. The thermal mounting in these experiments had a measured equivalent conductivity of 0.01 BTU/hr °F and supported roughly 0.5 lb. Conservative scaling to 200 lb using a 2/3 power relation (weight $\propto$ strength $\propto$ mount area) results in a conductivity of ~0.54 BTU/hr °F for the mounts required for all four main stacks in each tray. Assuming a constant external temperature 19° C (34° F) above the stack temperature (this is quite conservative since the external temperature does not remain at its maximum value over the entire orbit), we obtain a heat input of 14 BTU during one half-orbit. The heat capacity of all four stacks is 16 BTU/°F, resulting in a maximum excursion of ~0.9° F (0.5° C) during an orbit.

Since long-term variation of the stack temperature is unavoidable on LDEF, some means must be found to record the temperature of the stack for each event so that this can be incorporated in the data analysis procedure, much in the same way that temperature measurements for active detectors are used to correct phototube and electronic drifts. The simplest way of incorporating such an "event thermometer" into a passive LDEF experiment is to use a sliding CR-39 sheet which is driven by bimetal strips in response to temperature changes. The displacement of each track in this sheet with respect to its companion in the fixed stack below can be used to determine the temperature of the stack for each event. The stack cannister will be filled with 0.2 atm O_2 to simulate the normal external oxygen environment and thus insure proper track preservation while at the same time providing a reduced total pressure within the module. On launch and landing, when the external pressure is 1 atm, the cannister top will be compressed and the event thermometer will be captured between the stack and the top honeycomb panel (see Fig. 9) to protect it from acoustical loads. In orbit, the cannister will inflate to fill the aluminum honeycomb cannister enclosure and the event thermometer will be free to move. Three pairs of spring-loaded delrin slides will provide a constant force on the movable panel to ensure smooth operation. The event thermometer will slide by ±0.5 cm for a temperature variation of ±30° C. A 1° C change in temperature will correspond to a 170 μm shift, which is easily measurable with an optical microscope.

9. Effect of Trapped Radiation and Cosmic Ray Proton Background

An important feature of plastic track detectors that makes them ideally suited for an ultraheavy cosmic ray experiment is their ability to record highly ionizing particles without recording lightly ionizing particles. As a result, the more than 10^7 high-energy cosmic ray protons and helium nuclei which will pass through each square cm of the LDEF-II detectors will not leave individual tracks which would interfere with the tracks of ultraheavy nuclei. Low-energy recoil proton tracks due to collisions of high-energy protons with hydrogen in the CR-39 do result in short, visible tracks. Recoiling nuclei of light elements such as helium and carbon will also produce tracks but in much smaller number. The dominant contribution to background tracks for the second LDEF will come from nuclear reactions of medium-energy protons in the trapped radiation belts. Protons with an energy less than ~30 MeV have insufficient energy to reach the plastic detectors through the overlying material, and protons with an energy exceeding ~100 MeV would pass through the entire stack. Rather than attempt to calculate the effects of trapped protons, we simulated exposures of CR-39 to trapped radiation using 25 MeV protons from the Lawrence Berkeley Laboratory's 88" cyclotron.[7] We found that for every 2000 protons incident on CR-39, one small track of a nuclear recoil particle was produced. At solar minimum, the nominal average flux of trapped protons integrated along various orbits for one year is summarized below.[8]

	30° Orbit	60° Orbit
	Flux ($cm^{-2}\ y^{-1}$)	Flux ($cm^{-2}\ y^{-1}$)
Altitude	E $\geq$ 30 MeV	E $\geq$ 30 MeV
150 nm (278 km)	6.6×10^7	7.7×10^7
225 nm (417 km)	4.4×10^8	4.4×10^8
300 nm (556 km)	2.4×10^9	1.5×10^9

The trapped radiation falls off very steeply with altitude. At altitudes up to 225 nautical miles the flux of protons for a two-year exposure at solar minimum will be less than $5 \times 10^9/cm^2$. Using this number and the 1/2000 efficiency for producing tracks we find that the maximum density of small pits produced in the LDEF-II CR-39 detectors will be $\sim 2.5 \times 10^{-3}/\mu m^2$. This is comparable to the flaw density observed in the CR-39 sheets used for the charge resolution studies mentioned earlier and hence we do not anticipate that the trapped radiation will present a serious problem. Furthermore, use of an etchant composed of alcohol and water as we have described previously will render the CR-39 completely insensitive to the majority of these tracks.

Bulk irradiation of the plastic detectors in the LDEF-II experiment will total no more than ~2000 rads. For Lexan exposed outside Skylab, there was no degradation due to exposure to trapped protons. While it is true that CR-39 is more sensitive than Lexan, significant changes in the general etch rate have been observed by us to occur only after exposure to more than 2 Mrad.[7] This is three orders of magnitude larger than the dose expected and thus any effects on the resolution of CR-39 detectors should be completely negligible.

References

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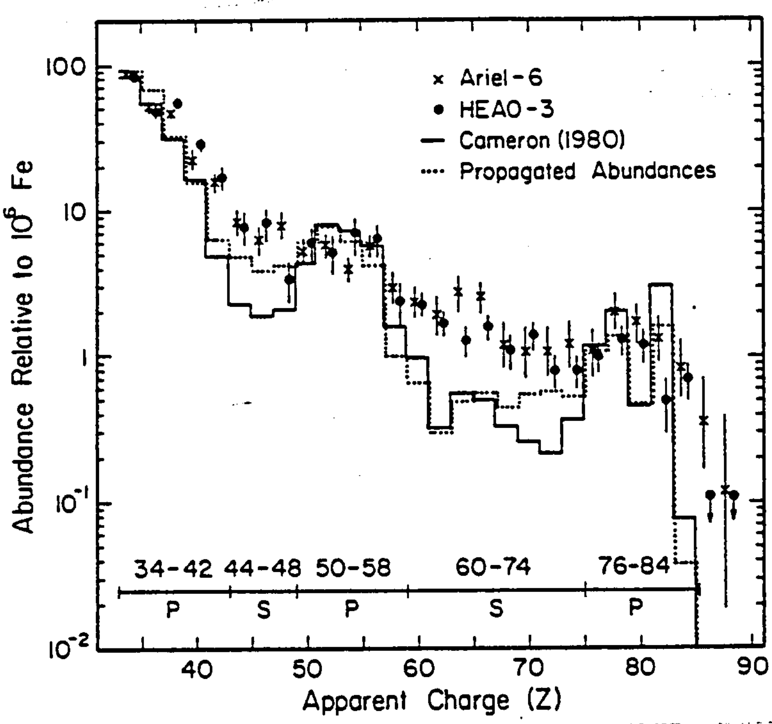

Figure 1. Ultraheavy cosmic ray abundances in 2-charge-unit bins (Fe = 10^6). Charge assignments are preliminary and assume Z^2 dependence. Propagated abundances assume a solar system source and a mean path length of 5.5 g/cm^2 in the interstellar medium

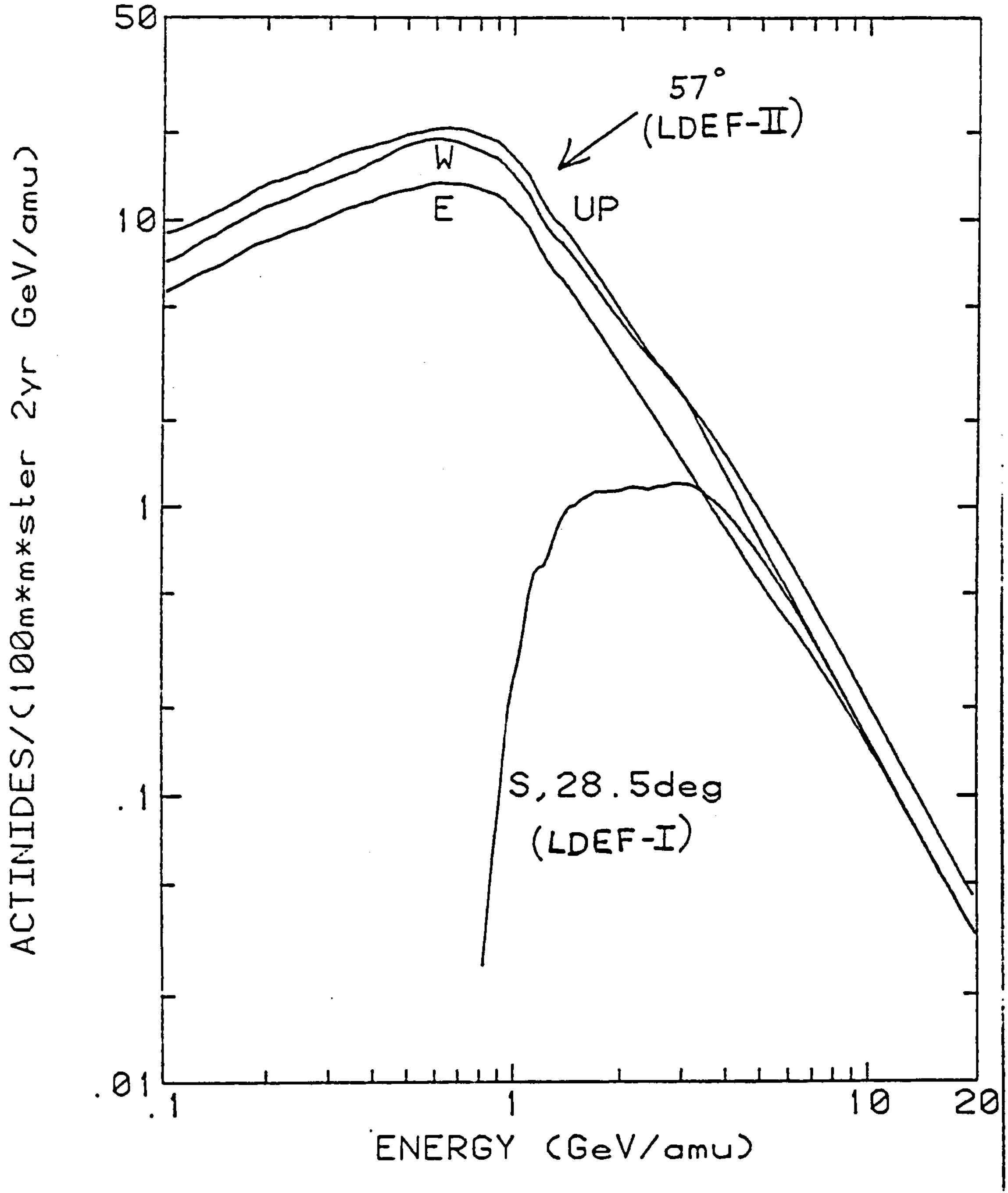

Figure 2. Calculated rate of arrival of nuclei with $Z \geq 90$ at detectors pointing in several directions and in 28.5° and 57° orbits as a function of energy. All fluxes should be multiplied by 1.5.

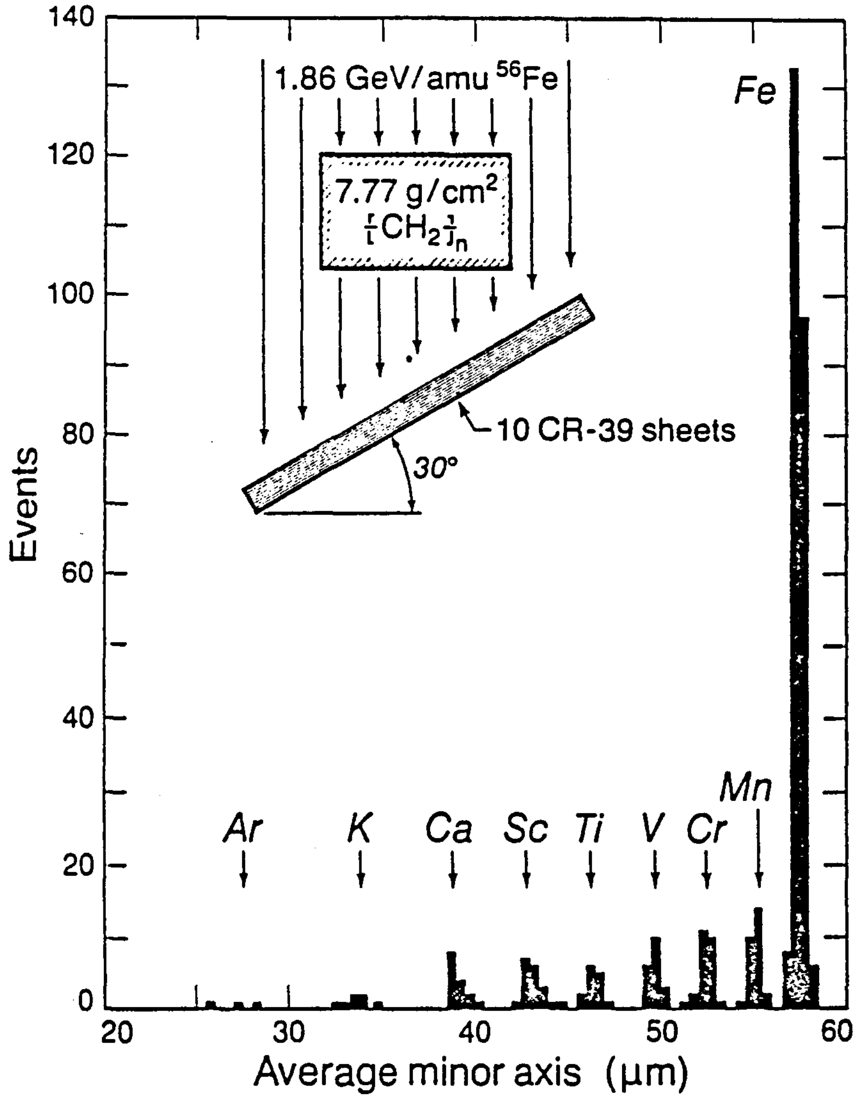

Figure 3. An example of the high charge resolution of CR-39 exposed to relativistic heavy ions in the LBL Bevalac.

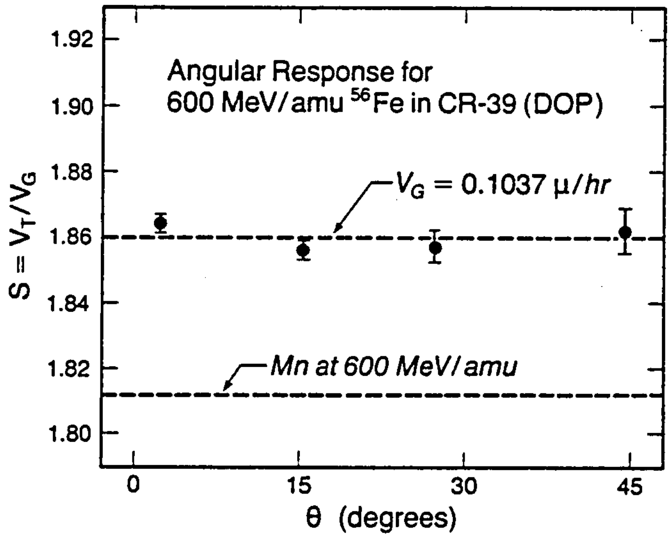

Figure 4. Demonstration that response of CR-39 is independent of zenith angle of entry of the particles.

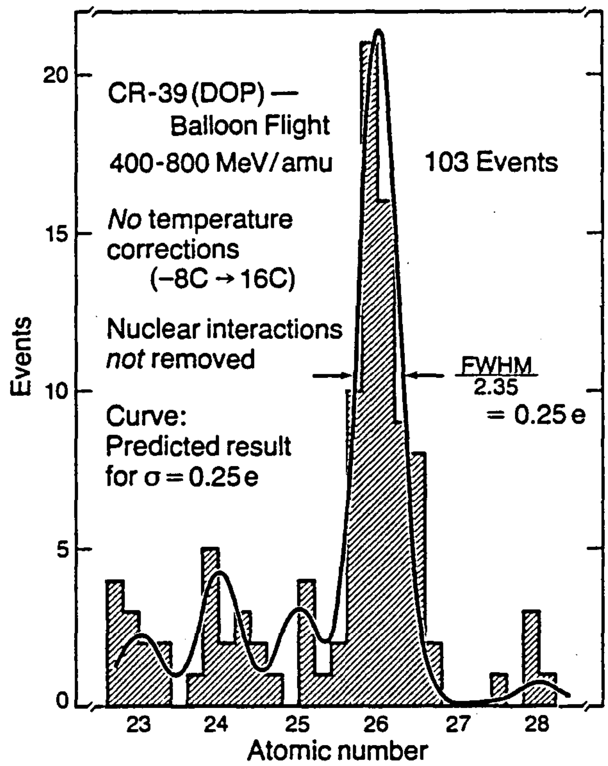

Figure 5. Demonstration of the high charge resolution of CR-39 exposed to cosmic rays in a balloon flight.

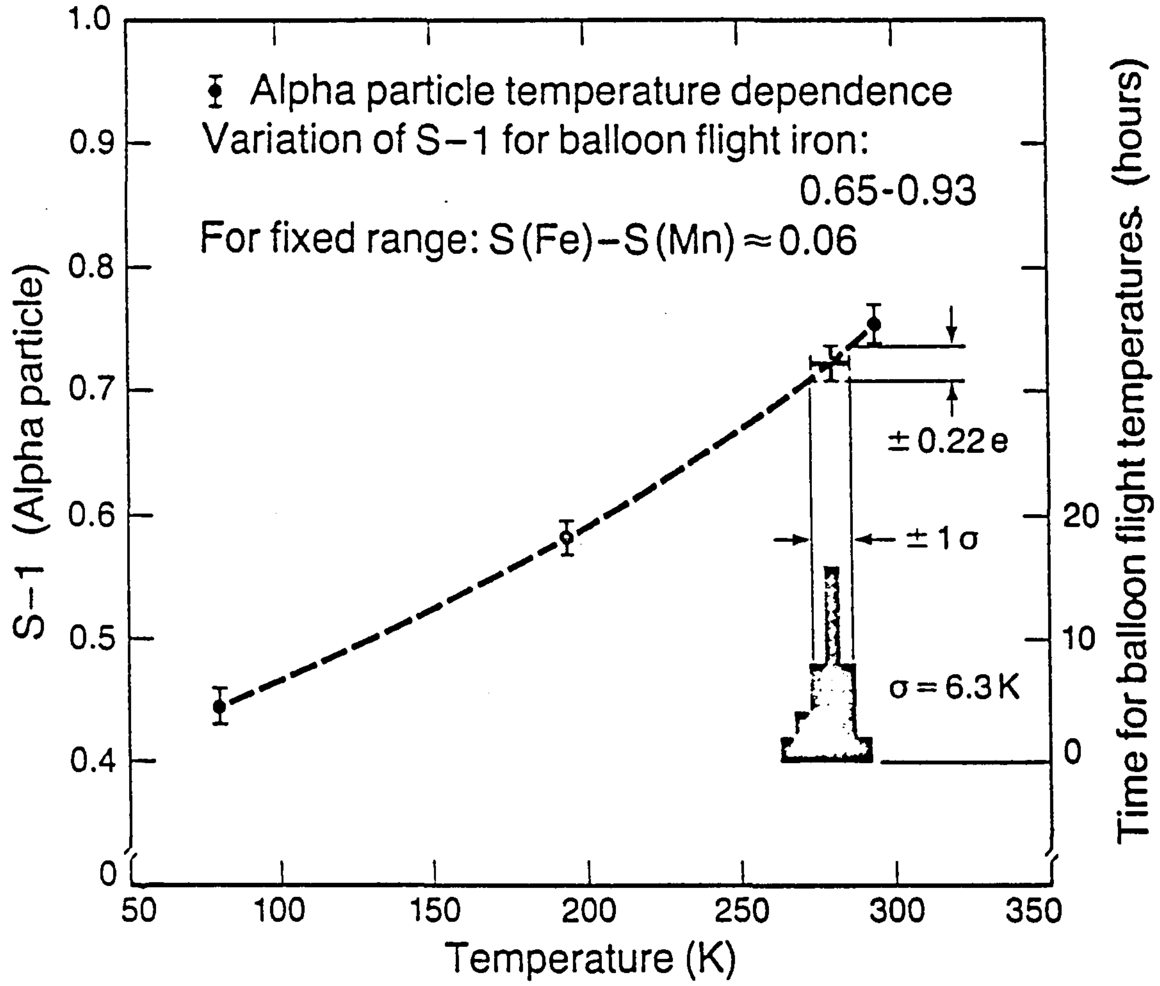

Figure 6. Temperature dependence of response to alpha-particles with Z/β similar to that of relativistic iron nuclei.

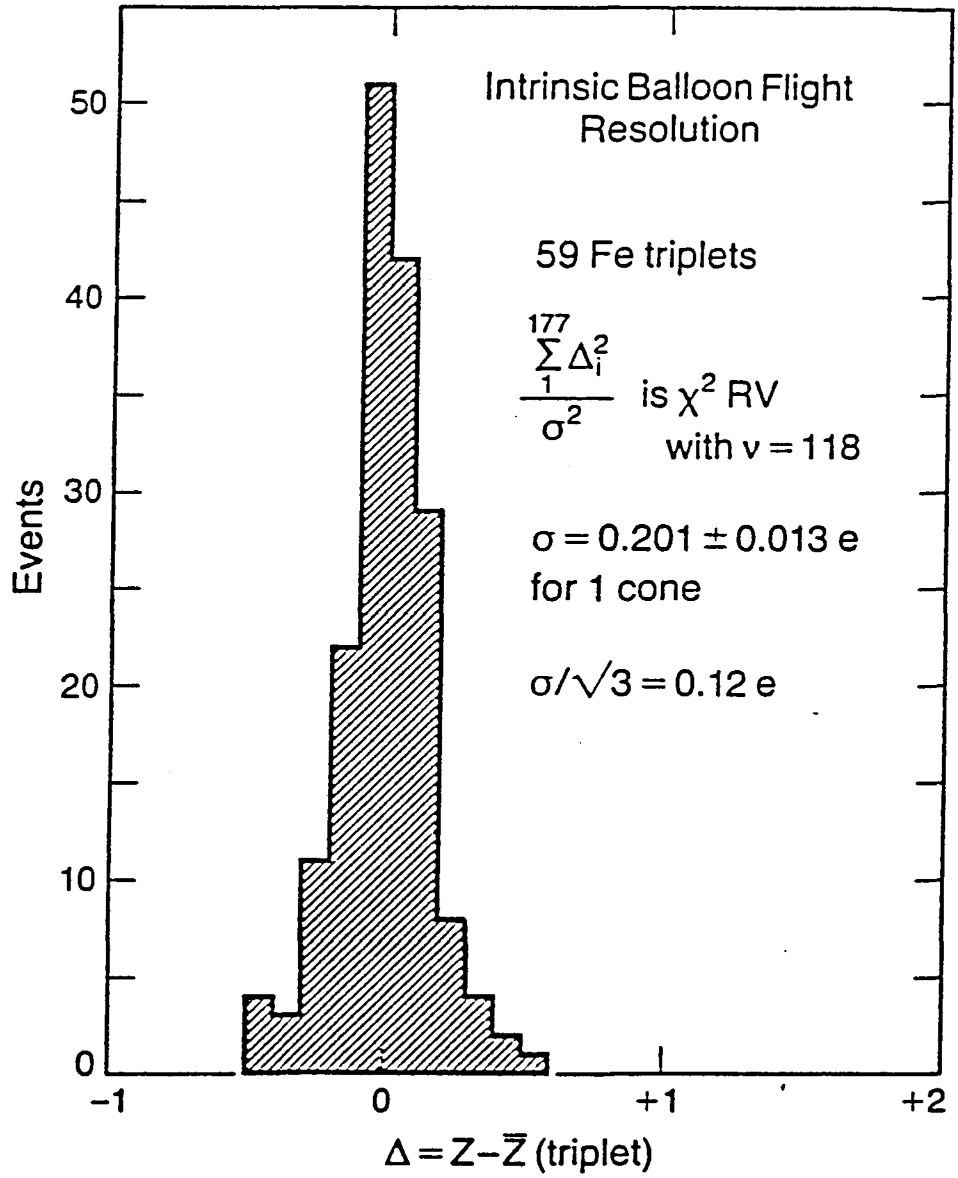

Figure 7. Intrinsic resolution as determined from balloon flight, in absence of temperature variations or possible zenith angle effects.

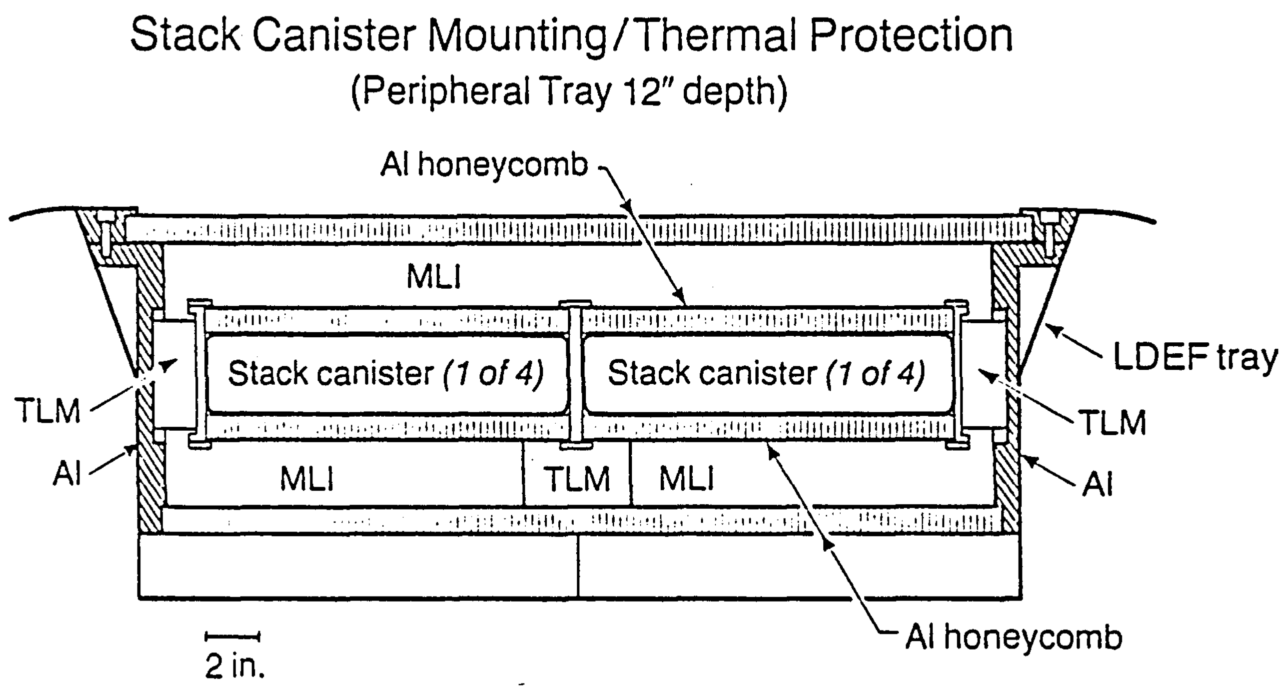

Figure 8. Overall view of mounting arrangement for four cannisters in our LDEF tray.

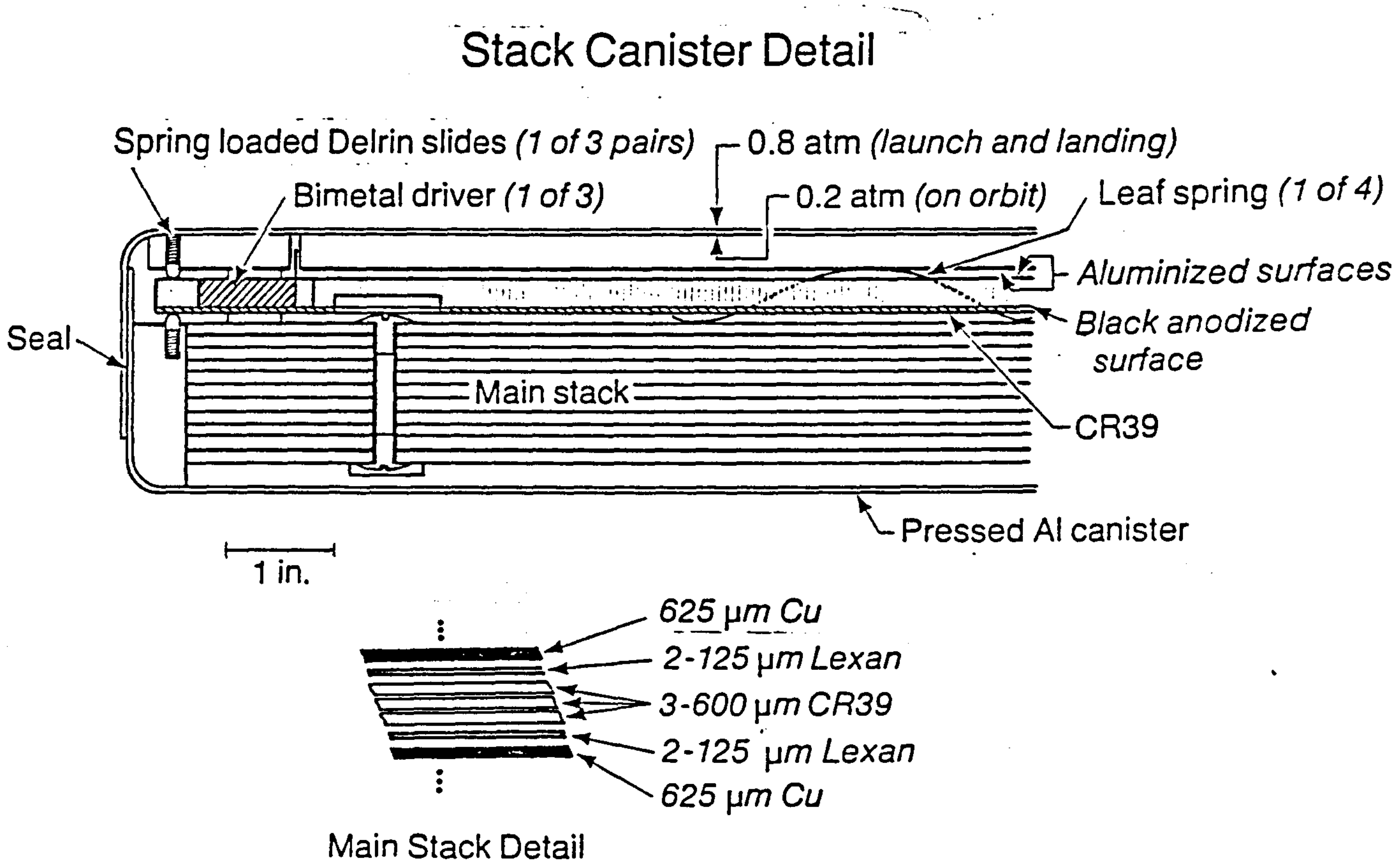

Figure 9. Detail of stack contents and event thermometer.

PART II

Management and Cost Plan

1. Guiding Principles

Initially the major concern is to gain the support of NASA management for the concept of using an LDEF reflight to achieve the scientific goal, endorsed by the Cosmic Ray Program Working Group, of an ultraheavy cosmic ray experiment of high resolution and collecting power.

We propose to leave the detailed strategy for getting the project approved to Dr. Albert Opp at NASA Headquarters. One possible mode would be for NASA Headquarters to indicate when it would be appropriate to receive an unsolicited proposal to do the ultraheavy cosmic ray experiment as well as unsolicited proposals to do smaller experiments on the same LDEF reflight.

At an appropriate time NASA Headquarters could announce an opportunity for Guest Investigators with a published record of successful cosmic ray experiments to prepare their laboratories to share in analysis of the large volume of data expected. The timing of this AO should be left to Dr. Opp.

After the mission is approved the major concern then shifts to the construction of detectors, event thermometers, and hardware of uniform quality and performance. The remainder of this Management Plan is written with the assumption that the experiment will be constructed at the University of California, Berkeley, Space Sciences Laboratory.

2. Experiment Construction

A. Management Plan

1. General

The key personnel will be the Principal Investigator, Project Scientist, and Project Manager, supported by Space Sciences Laboratory staff such as the Executive Officer, Contracts and Grants Officer, Purchasing Unit, Accounting Unit, and administrative and secretarial assistance as needed.

Basic management functions will be provided by the Principal Investigator, who will have overall responsibility for timely construction, testing, and delivery of the experiment and for post-flight analysis. The Project Scientist will be responsible for the final design and construction of the detector modules, for development and operation of equipment used for post-flight analysis, and for supervision of the personnel used during detector assembly and post-flight analysis. The Project Engineer, who will double as the Project Manager during the two-year construction phase, will manage the design of the payload exclusive of the detector modules and the acquisition and fabrication of mechanical components. One Assistant Research Physicist will participate in the final design and construction phase. Another Assistant Research Physicist and one graduate student research assistant will participate in the data analysis and interpretation. The graduate student will choose a portion of the data from which to develop a Ph.D. thesis.

We plan to construct the payload at the Space Sciences Laboratory, subcontracting certain elements of the hardware. That is the simplest and least expensive approach. We have experience in making track detector arrays for balloon flights and our Skylab detector. Space Sciences Laboratory (SSL) has a proven record of success in designing and constructing large payloads. Professor Pimentel's Mariner-Mars Mission and Professor Bowyer's upcoming EUV Explorer satellite are excellent examples of the complexity of experiments that SSL is capable of constructing. For the EUV Explorer, SSL will build all four EUV telescopes, increasing its staff by roughly 40 new scientists, engineers and technicians to carry out this project during the next several years. To construct the detectors for LDEF-II and to assemble them into cannisters will be much simpler than to build the EUV detectors. Redundancy in design for the 61 LDEF trays will result in an enormous savings in time and cost.

The major components of the package structure are simple machined parts made from standard extrusions and materials. Both the Space Sciences Lab and the Physics Department have shops capable of making all of the machined parts.

The precision rolling and cutting of the copper sheets, the casting of the CR-39 detector sheets and the laser cutting of the CR-39 sheets before and after flight will be performed by subcontractors.

Testing of the monomer used in the casting of the CR-39 used in the experiment will be performed by the Project Scientist at the U.C. Berkeley Chemistry Department. We have already identified several major impurities in CR-39 monomer which affect the quality of the cast plastic for track work. The level of these impurities varies from batch to batch in monomer received from PPG Industries (the U.S. supplier) and batches with the proper composition will be selected before casting of the actual flight detectors. Analysis procedures using gas chromatography (GC) and High Pressure Liquid Chromatography (HPLC) have already been standardized.

Testing of the cast CR-39 will be performed by the Project Scientist using beams available at the Lawrence Berkeley Laboratory (LBL) 88" cyclotron and Bevalac. Bulk irradiation testing will be performed using LBL's 3000 Ci ^{60}Co source.

Testing of the operation of the event thermometers will be performed in environmental test chambers at the Space Sciences Laboratory.

2. Facilities and Equipment

The components of the payload structure will be fabricated primarily in the machine shops of the U.C. Berkeley Space Sciences Laboratory and the U.C. Berkeley Physics Department. Some components will be subcontracted to local commercial machine shops. The detector modules consist of layers of Lexan, CR-39, copper and an event thermometer sealed in an aluminum cannister at reduced pressure. The Lexan sheets will be pre-cut to size by the suppliers. The CR-39 sheets will be laser-cut by a subcontractor to insure cleanliness and to reduce cutting costs. The copper will be rolled and cut to size by a subcontractor. The event thermometer will be fabricated in-house.

We will obtain the monomer for the CR-39 from a commercial supplier and then characterize the impurities at the U.C. Berkeley Chemistry Department. The monomer will be shipped to a commercial casting firm to be cast into sheets. Samples of these detectors will be tested using accelerators and radioactive sources at LBL. The proximity of LBL to SSL is very fortunate since many of the critical tests must be performed using the LBL Bevalac, which is the only facility of its kind in the world.

Assembly of the entire payload will require a large, relatively clean area in the Space Sciences building. The Regents of the University of California have approved funds to refurbish a large basement area at SSL with clean rooms where EUV telescopes can be calibrated and where we can construct and assemble the LDEF-II detectors.

After assembly, the completed LDEF trays will be shipped to Langley Research Center for integration in the LDEF.

Payload operation during the two year mission will require a minimum of experimenter support. We plan to use these two years to upgrade our etching facilities for use with alcoholic etchants and to develop hardware and software to be used to collect data from microscope stations. A Senior Developmental Engineer will be required during this time to interface the computer to the microscope stations and to develop specialized hardware for adapting standard microscopes for rapid measurements.

The major effort involved in the experiment begins when the exposed detectors are returned to our laboratory. The modules must be disassembled and stored. Selected Lexan sheets etched in temperature-controlled baths of NaOH will be scanned with ammonia and blue-print paper to search for punch-through tracks due to the heaviest cosmic rays. Selected sections of CR-39 and Lexan will be cut out along the trajectory of these particles and will be etched and then measured in high-power microscopes connected to a minicomputer. Final data reduction can be performed using this same computer.

Most of the necessary space and equipment already exist. The experiment will require several new high-power microscopes to augment our present microscopes. Several video terminals, a computer and computer interface will be required to replace our present aging and marginally reliable computer.

Preliminary Budget - IN CONSTANT 1982 DOLLARS.

PART I - PREFLIGHT (Years 1 & 2).

A. Salaries and Wages	Man-Months Yr.1/Yr.2	Monthly Rates†	Amounts Requested Year 1	Year 2	
Professor VII (P.I.) (summer)	1.5/1.5	$5722	$8,583	$8,583	Δ
Asst.Rsrch.Phys. V (Project Scientist)	12.0/12.0	2375	28,500	28,500	*
Assistant Research Physicist I	12.0/12.0	1908	22,896	22,896	*
Assoc.Devel.Engr. (Project Manager)	12.0/12.0	2378/2492	28,536	29,904	**
Staff Research Associate II/III	6.0/ --	1926	11,556	--	**
	6.0/6.0	2019	12,114	12,114	**
	-- /6.0	2115	--	12,690	**
3 Research Assistants	9.0/9.0	1258	11,322	11,322	Δ
	13.5/13.5	1258	16,983	16,983	ΔΔ
Administrative Assistant II	9.0/9.0	1433/1496	12,897	13,464	**
Secretary III	3.0/3.0	1566	4,698	4,698	**
Support Personnel††	---	--	4,320	4,380	**
			$162,405	$165,539	

†Same for both years in a constant-dollar budget, unless one rate for each year is shown.

††SSL staff personnel (accounting, payroll, etc.) who are not state or University-supported, at an average cost of $360/mo. (yr. 1) & $365/mo. (yr. 2).

B. Employee Benefits	Year 1	Year 2
For salaries marked *, 29½% in yr. 1 & 30½% in yr. 2	$15,162	$15,676
For salaries marked **, 28½% in yr. 1 & 29½% in yr. 2	21,124	22,790
For salaries marked Δ, 1.93% in both years	384	384
For salaries marked ΔΔ, 1.08% in both years	183	183
	$36,853	$39,033

C. Supplies and Expenses	Year 1	Year 2
Subcontract for monomer quality control testing	$20,000	--
Environmental testing; Bevelac and balloon flight testing	50,000	$50,000
Communications and miscellaneous supplies and expenses	24,000	24,000
	$94,000	$74,000

D. Equipment

Fabrication of ultraheay cosmic ray detector, based on the following estimates of component costs:

	Year 1	Year 2
CR-39	$160,000	--
Subcontract for laser cutting of CR-39	15,000	--
Lexan (cut)	11,000	--
Copper shim stock	15,000	--
Subcontract for copper rolling	110,000	--
Mounting hardware & materials (cannisters, honeycomb panel, thermal mounts, blankets, etc.)	100,000	--
Subcontract for assembly of mounting hardware	100,000	--
SSL machine shop labor - 1,920 hrs. @ $23.25/hr.	44,640	--
Environmental testing apparatus	30,000	--

continued

Preliminary budget (continued) - IN CONSTANT 1982 DOLLARS

Part I - Preflight (continued)

	Amounts Requested	
D. Equipment (continued)	Year 1	Year 2
Purging apparatus	$10,000	—
Assembly jigs	30,000	—
	$625,640	-0-
E. Travel		
4 3-day RT to Washington, D.C. for 1 person, per year	$4,760	$4,760
Total Direct Costs	$923,658	$283,332
Indirect Costs - 24½% MTDC (provisional after 7/1/82)	$73,014	$69,416
TOTAL AMOUNT REQUESTED PER YEAR	$996,672	$352,748

Preliminary budget (continued) - IN CONSTANT 1982 DOLLARS

PART II - FLIGHT (Years 3 & 4).

A. Salaries and Wages	Man-Months Yr.3/Yr.4	Monthly Rates†	Amounts Requested Year 3	Year 4	
Assoc.Rsrch.Phys.II (Project Scientist)	12.0/12.0	$2517	$30,204	$30,204	*
Assoc.Devel.Engr. (Project Manager)	12.0/12.0	2613/2737	31,356	32,844	**
Staff Research Associate III/IV	12.0/6.0	2115	25,380	12,690	**
	-- /6.0	2218	--	13,308	**
Programmer I	-- /12.0	1972	--	23,664	**
Research Assistant	-- /3.0	1258	--	3,774	Δ
	-- /4.5	1258	--	5,661	ΔΔ
Administrative Assistant II	6.0/6.0	1566	9,396	9,396	**
Secretary III	0.5/0.5	1566	783	783	**
Support Personnel††	---	--	2,580	3,540	**
			$99,699	$135,864	

†Same for both years in this phase of the constant-dollar budget.
††SSL staff personnel (accounting, payroll, etc.) who are not state or University-supported, at an average cost of $215/mo. (yr. 3) & $295/mo. (yr. 4).

B. Employee Benefits	Year 3	Year 4
For salaries marked *, 31½% in both years	$9,514	$9,514
For salaries marked **, 30½% in both years	21,196	29,349
For salaries marked Δ, 1.93%	--	73
For salaries marked ΔΔ, 1.08%	--	61
	$30,710	$38,997

C. Supplies and Expenses	Year 3	Year 4
Chemicals and etchants	$2,000	$4,000
Computer supplies	4,000	4,000
Communications and miscellaneous supplies and expenses	12,000	12,000
	$18,000	$20,000

D. Equipment	Year 3	Year 4
PDP-11 computer system, and peripherals	$161,000	--
4 microscope stations with interfaces @ $30,000 ea.	120,000	--
Etching equipment	50,000	--
	$331,000	-0-

	Year 3	Year 4
E. Travel - 2 3-day RT to Wash., D.C. for 1 person, per year	$2,380	$2,380
Total Direct Costs	$481,789	$197,241
Indirect Costs - 24½% MTDC (provisional after 7/1/82)	$36,943	$48,324
TOTAL AMOUNT REQUESTED PER YEAR	$518,732	$245,565

Preliminary budget (continued) - IN CONSTANT 1982 DOLLARS

PART III - POSTFLIGHT (Years 5 & 6).

A. Salaries and Wages	Man-Months Yr.5/Yr.6	Monthly Rates†	Amounts Requested Year 5	Year 6	
Assoc.Rsrch.Phys.III (Project Scientist)	12.0/12.0	$2675	$32,100	$32,100	*
Assistant Research Physicist III	12.0/12.0	2100	25,200	25,200	*
Staff Research Associate IV	6.0/ --	2218	13,308	—	**
	6.0/12.0	2322	13,932	27,864	**
Programmer I	12.0/12.0	2066/2167	24,792	26,004	**
Research Assistant	3.0/3.0	1258	3,774	3,774	Δ
	4.5/4.5	1258	5,661	5,661	ΔΔ
2 Laboratory Assistants I	24.0/24.0	1023/1063	24,552	25,512	**
4 Scanners II	48.0/48.0	1063/1101	51,024	52,848	**
Secretary III	3.0/3.0	1566	4,698	4,698	**
Support Personnel††	—	—	5,340	5,460	**
			$204,381	$209,121	

†Same for both years in a constant-dollar budget, unless one rate for each year is shown.

††SSL staff personnel (accounting, payroll, etc.) who are not state or University-supported, at an average cost of $445/mo. (yr. 5) & $455/mo. (yr. 6).

B. Employee Benefits	Year 5	Year 6
For salaries marked *, 31½% in both years	$18,050	$18,050
For salaries marked **, 30½% in both years	41,982	43,428
For salaries marked Δ, 1.93% in both years	73	73
For salaries marked ΔΔ, 1.08% in both years	61	61
	$60,166	$61,612

C. Supplies and Expenses	Year 5	Year 6
Chemicals and etchants	$50,000	$5,000
Subcontract for laser/mechanical cutting of exposed detectors	40,000	—
Computer supplies	4,000	4,000
Publication costs (page charges)	4,000	6,000
Communications and miscellaneous supplies and expenses	12,000	12,000
	$110,000	$27,000

D. Travel	Year 5	Year 6
2 3-day RT to Washington, D.C. for 1 person	$2,380	—
3 3-day RT for Washington, D.C. for 1 person	--	$3,570
	$2,380	$3,570

	Year 5	Year 6
Total Direct Costs	$376,927	$301,303
Indirect Costs - 24½% MTDC (provisional after 7/1/82)	$88,672	$73,819
TOTAL AMOUNT REQUESTED PER YEAR	$465,599	$375,122

BUDGET SUMMARY

Phase		Project Year	Amount Per Year	Phase Subtotals
I	-- Preflight	1	$996,672	
		2	352,748	$1,349,420
II	-- Flight	3	518,732	
		4	245,565	764,297
III	-- Postflight	5	465,599	
		6	375,122	840,721
TOTAL AMOUNT REQUESTED FOR PROJECT			$2,954,438	

Notes

1. Re. time period of project -- for purposes of estimating promotions and merit increases for budgeted personnel, a contract start date of July 1, 1983 was assumed. This simplified the budget, in that most promotions and merit increases at the University have July 1 effective dates; thus no budget year has more than one salary rate per person.

2. Re. the constant-dollar feature -- although promotions were figured into the budget, current rates for the projected titles or steps were used. Cost-of-living increases were not projected, nor were any other inflation factors applied to any cost item.

3. Re. indirect costs -- the agreement between the Federal Government and the University that established pre-determined overhead rates for sponsored projects will expire on June 30, 1982. New rates have not yet been negotiated, but can be expected to be higher.

APPENDIX

Prototype Development

Prototype Development

A prototype development phase is required to perform detailed engineering studies for the thermal and mechanical design and to fabricate a protype LDEF tray which can be used to verify the design principles by means of thermal vacuum tests.

Two specific items which must be studied in detail are the Thermal Labyrinth Mounts and the event thermometer. A thermal analysis computer model will be established for both the individual modules and their mounting enclosures and the LDEF exterior blanket. This model will enable us to optimize the total detector surface area, determine the thermal mounting requirements and accurately predict the maximum detector temperature excursions expected during the mission. The event thermometers will be designed to accommodate (with an adequate safety factor) this predicted range of temperatures. The final product of the engineering studies will be a set of detailed drawings from which a prototype tray can be constructed.

The prototype tray will be identical to the final LDEF experiment trays except that it will contain three dummy stack cannisters and only one complete cannister. The dummy cannisters will simulate the thermal and mechanical properties of actual cannisters. The complete cannister will be instrumented with thermisters to verify the thermal model and with a position encoder to verify the correct operation of the event thermometer. The prototype tray will be constructed at the Space Sciences Laboratory with certain items such as the laser cutting of the CR-39 and some mechanical assembly to be performed by local subcontractors. We expect that an empty, 12"-deep, peripheral LDEF tray will be provided by the LDEF Project Office.

Thermal vacuum testing of the entire tray will be performed at Langley Research Center. The tray will be subjected to a thermal and pressure environment which will simulate that expected in the actual LDEF flight. During this time the temperature uniformity and thermal response time of the stack will be monitored by the thermisters while the position encoder will check that the event thermometer releases properly under vacuum conditions and then tracks the stack temperature within the specified limits.

The following budget is for prototype development. At least $10,000 could be saved if Bill Hibbard or another thermal engineer at Goddard could participate in this development, so that we would not have to use a Senior Development Engineer at SSL.

Prototype Development Phase Budget, April 1, 1982 - August 31, 1983 (17 months), subdivided by Federal fiscal year. (Not in constant dollars).

A. Salaries and Wages	Man Months	Monthly Rate†	Amts. Requested Per FY (6 mos.) 4/1/82-9/30/82	(11 mos.) 10/1/82-8/31/83	
Assistant Research Physicist IV	1.00	$2233	$2,233	—	*
(Project Scientist)	0.25	2423	606	—	*
	1.50	2423	--	$3,635	*
	0.25	2629	—	657	*
Senior Development Engineer	2.00	3307	6,614	—	
	1.00	3588	3,588	--	
	1.00	3588	—	3,588	
Staff Research Associate II	1.00	1995	1,995	—	
	1.50	1995	--	2,993	
	3.50	2090	—	7,315	
Secretary III	0.25	1699	425	—	
	0.50	1699	850	—	
	0.25	1843	--	461	
Support Personnel††	—	--	450	825	
			$16,761	$19,474	

†Includes anticipated 8½% cost of living increases effective 7/1/82 and 7/1/83.
††SSL staff personnel (accounting, payroll, etc.) who are not state or University-supported, at an average cost of $75/mo.

B. Employee Benefits		
For salaries marked *, 28% in 1st period and 28.5% in 2nd	$795	$1,223
For all other salaries, 27% in 1st period and 27.5% in 2nd	3,759	4,175
	$4,554	$5,398

C. Supplies and Expenses		
Air freight shipment of prototype and test equipment to Langley RC and return, for thermal vacuum testing	—	$1,600
Communications and miscellaneous supplies and expenses	$301	501
	$301	$2,101

D. Equipment

Fabrication of prototype ultraheavy cosmic ray detector, based on the following estimates of component costs:

CR-39 and lexan	$5,000	—
Subcontract for laser/mechanical cutting of detectors	6,000	--
Copper sheets	2,000	—
Mounting hardware and materials	8,000	—
Electronics - thermistors, position encoders, etc.	—	$5,000
SSL machine shop labor - 240 hrs. @ $25/hr.	6,000	--
- 280 hrs. @ $25/hr.	--	7,000
	$27,000	$12,000

continued

Prototype development phase budget (continued) - not in constant dollars

	Amts. Requested Per FY (6 mos.) 4/1/82-9/30/82	Amts. Requested Per FY (11 mos.) 10/1/82-8/31/83
F. Travel		
1 2-week RT to Langley RC for 2 people, for thermal vacuum testing of prototype	--	$3,620
Total Direct Costs	$48,616	$42,593
Indirect Costs - 24.5% of modified total direct costs (rate provisional after 7/1/82)	$5,296	$7,495
TOTAL AMOUNT REQUESTED PER PERIOD	$53,912	$50,088
TOTAL AMOUNT REQUESTED	$104,000	

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15. Supplementary Notes

Langley Technical Representative: James L. Jones, Jr.
Final Report

16. Abstract

To achieve the goals of cosmic ray astrophysics, an ultraheavy cosmic ray experiment on an LDEF reflight should be in an orbit with high inclination (~57°) at ~230 nm for ~2 years near solar minimum (~1986). It should fill 61 trays. Each tray should contain 4 modules of total active area 0.7 m^2, with a thermal blanket, thermal labyrinth mounts, aluminum honeycomb mechanical support, and total weight ~100 kg. Each module should contain interleaved CR39, Lexan, and thin copper sheets plus one event-thermometer canned in a thin metal cannister sealed with ~0.2 atm dry O_2. The CR39 and Lexan should be manufactured to our specifications. The sheet copper will be rolled to our specifications. The event-thermometer should be a stiffened CR39 sheet that slides via bimetal strips relative to fixed CR39 sheet so that stack temperature can be read out for each event. The metal cannister will be collapsed at launch and landing, capturing the sliding assembly to prevent damage. An engineering study should be made of a prototype LDEF tray; this will include thermal and mechanical tests of detectors and the event thermometer.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
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