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COLLECTION, ANALYSIS, AND ARCHIVAL OF LDEF ACTIVATION DATA*

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SUMMARY

The study of the induced radioactivity of samples intentionally placed aboard the Long Duration Exposure Facility (LDEF) and samples obtained from the LDEF structure is reviewed. The eight laboratories involved in the gamma-ray counting are listed and the scientists and the associated counting facilities are described. Presently, most of the gamma-ray counting has been completed and the spectra are being analyzed and corrected for efficiency and self absorption. The acquired spectra are being collected at Eastern Kentucky University for future reference. The results of these analyses are being compiled and reviewed for possible inconsistencies as well as for comparison with model calculations. These model calculations are being revised to include the changes in trapped-proton flux caused by the onset of the period of maximum solar activity and the rapidly decreasing spacecraft orbit. Tentative plans are given for the storage of the approximately 1000 gamma-ray spectra acquired in this study and the related experimental data.

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INTRODUCTION

Samples intentionally placed aboard the Long Duration Exposure Facility (LDEF) and samples obtained from the LDEF structure have been studied at NASA Marshall Space Flight Center and seven national laboratories to determine the specific radioactivity produced in orbit. The gamma-ray spectra from these studies have provided information concerning the type and quantity of radioactive nuclei produced by various activating particles. The gamma-ray spectra, the resulting activation, and the experimental arrangements are being collected at Marshall Space Flight Center and Eastern Kentucky University for review, further analysis, and future archival. An overview of this process and the type of information that will be available for future reference will be given here. This information includes the samples studied, the location of the samples on LDEF, the amount and type of covering material, the types of detector systems, the format of the gamma-ray spectra and the corrections for geometry, self-absorption, detector efficiency and background needed to obtain accurate specific activities (activation per kilogram) of material. Tentative plans are given as to the archival of the data for such future reference and how other scientific investigators or spacecraft designers can access the data.

DATA COLLECTION

Approximately 400 samples[1] have been obtained from LDEF and most, if not all, have been studied for radioactivity at one or more of seven counting facilities. The LDEF activation samples include 20 elementally pure rectangular slabs of original 2" x 2" x 1/8" dimensions although some were cut to smaller dimensions for mounting. The slabs are made from the elements V, Ni, Co, In, and Ta. The first three elements (V,Ni,Co) represent materials having very well-known cross sections for proton-induced reactions up to 200 MeV[2] and fairly well known cross sections up to 1 GeV or higher.[3] The last two samples have well known large thermal neutron cross sections[4] and have recently been studied for incident protons up to 200 MeV[3] and for neutrons at 200 MeV[5].

The samples of opportunity, or "unintentional" samples, include aluminum clamp plates and trays, titanium clips, lead ballast, and the stainless-steel trunnions.* The trunnions have been cut into 1/2-2 inch sections and sections D, G and L have been layered by cutting at different radial distances from the center. (See Figure 1 in ref. 6). Except for the outer layer(layer number 1),

*Harmon, B. A.: Space Science Laboratory, NASA/MSFC, private communication.

these layers were carefully flattened to give an approximate rectangular slab geometry. The aluminum pieces are of various shapes and sizes. In addition, bolts were taken from the structure and have been studied.

These samples, mostly having rectangular slab geometries, have been studied for radioactivity at MSFC and six other counting facilities. These facilities are listed in Table 1 along with the collaborating scientists. These facilities could be categorized as being shielded, low-background, and ultra-low background. A shielded facility is one where shielding is used primarily to prevent contamination from other samples being counted in a multiple sample count facility. The TVA/Muscle Shoals facility might be considered such a facility. Low-background facilities would have several inches of shielding consisting of layers of lead, stainless-steel (or copper), and aluminum. The facility at the Space Science Laboratory at MSFC could be categorized amongst these. The ultra-low background facilities often have a low background facility placed in an underground location. The facilities used by Bill Winn at SRL[6] and by Al Smith at LBL[7] are ultra-low-background facilities.

At SRL the facility is located in a clean room 50 feet underground with the equivalent of 104 feet of water shielding. (See Figure 1, ref. 6). At LBL, or rather at their Oroville Dam facility, the facility is located inside the dam under 600 feet of bedrock. Such locations with low-background arrangements make excellent facilities for very low-activity samples.

The detectors used in these facilities consist of low resolution large volume NaI detectors and HPGe and Ge(Li) high resolution gamma-ray detectors which in some cases possess active shielding in addition to the passive shielding already described. The NaI(Tl) detectors include the 4π detector at JSC as well as the one at PNWL already mentioned by Jim Reeves in this conference. The germanium detectors are efficiency rated in relation to a 3" diameter, 3" long NaI(Tl) detector at a gamma-ray energy of 1332 keV. Those used in these studies have efficiencies ranging up to 90%. With shielding and electronics these are definitely state-of-the-art systems.

Analysis

Most radioactivity studies are done with very small, moderately active samples placed 10-25 cm from the detector. Such a sample is considered to be a point source and the determination of the activity is greatly simplified. However, the LDEF samples are quite large and must be counted in close proximity to the detectors to accurately determine gamma-ray yields. In order to properly determine the activity, the efficiency of the detector for such an extended source must be determined and the correction for the self attenuation of the source must be made.

Each laboratory is responsible for determining the efficiency of their detectors and correcting for the self attenuation. The unique experimental arrangements of each laboratory prevent outside determination of these factors. However, to facilitate such corrections 2" x 2" mixed gamma-ray sources have been made by Charles Frederick of TVA and MSFC has prepared a stack of 2" x 2" stainless steel absorbers. These have been distributed to the counting laboratories to establish common reference data.

Figure 1 shows the efficiency of the HPGe detector at SSL/MSFC along with the fit found using an appropriate energy-dependent function:

$$\ln \varepsilon = a/E\gamma + b + c\,(\ln E\gamma) + d(\ln E\gamma)^2 + e(\ln E\gamma)^3.$$

Figure 3 of reference 6 shows similar efficiencies for the Los Alamos detectors at several different distances made with one of the 2" x 2" sources. These curves are typical of those obtained for HPGe detectors.

Since the absolute efficiency of these detectors decreases with distance between source and detector and with the increase of material between them, the absolute gamma-ray activities required a correction to the measured gamma-ray rate. Various laboratories have developed their own correction for efficiency and self attenuation. Bill Winn[6] has done a careful study of his systems and has developed an excellent model for these corrections. A similar model made for the MSFC detector has been incorporated into the inverse-square, self-absorption program EFFATN. This program was originally developed to correct spectra obtained from intentional samples activated with 200 MeV neutrons.[5] Figure 2(ref. 5) gives the activity of the 122 keV gamma rays from ^{57}Co taken through increasing thickness of stainless steel. The solid line is the predicted activity including inverse-square and self-absorption attenuation of this gamma ray. The plot was made using the average of the corrected activity through each absorber thickness. The "poor" fit at zero thickness may be due to incomplete correction for gamma-ray summing into the continuum. Such studies (results) indicate that these corrections can be accurately determined.

Table C-1.c of reference 7 from SRL shows an example of the exchange of samples. Consistent with the sharing of calibration sources and the exchange of samples is the goal of assuring that the results from the various counting laboratories are consistent. To date the data from the laboratories have been very consistent. A few comparisons currently being studied are shown in figures 3-6. Alan Harmon will present additional results in the next paper.

To date, a large set of resultant specific activities have been reported. Primarily, these have been from SRL, LLNL and LANL. They have been compiled to a spreadsheet and are currently being reviewed. They are being correlated with the position on LDEF so that the effects of the surrounding material may be determined. The shielding provided by the covering material, the moderation of thermal neutrons and the production of secondary particles will be studied in relation to sample specific activity.

The specific activity of each LDEF sample depends on the flux of activating particles, on the half-life of the decaying nuclei, and on the production cross section for the particular nuclei. The sample activities, therefore, will be significantly different from those originally estimated. The most significant reason for this is the rapid lowering of the LDEF orbit in the last two years and the transition from a period of minimum solar activity to one of maximum solar activity. Figure 7 shows the trapped proton flux at a proton energy of 50 MeV for various times in the LDEF-1 mission.[8] Figure 8 shows the projected activation rate for ^{54}Mn for the same time period. Obviously, short-lived radioisotopes will significantly decay in the last few months in the orbit. A careful prediction of the activation taking into account these reduced fluxes must be made for activation comparisons.

Archival

As the counting of the samples is nearing completion, we are planning the archival of the specific activities and the spectra obtained at the counting laboratories. To be stored with the spectra is a directory containing the specific details of the activation study. These include sample material, shape, dimensions, mass, and location on the spacecraft as well as detector efficiencies, energy calibrations, and self-attenuation corrections.

Perhaps as many as 1000 spectra will be available for future review. The spectra in the original binary format will be stored on a convenient magnetic media in a specified computer center. A catalog will specify the data acquisition system(ADCAM, ND66, Canberra 100, etc.) and will give the data format. Programs to change from one format to another will be available as well as general procedures to change to other formats. Figure 9 shows a sample spectrum from SRL which has been changed from the original ADCAM format to that for a Tennelec/Nucleus PCA-II system. Automatically analyzed peaks are indicated in the figures.

In addition, the spectra will be translated to a text format. Table 2 is a tentative sample of such a file from the SRL spectra. Included in the file is a channel number indicator in column 1 and a header giving the name of the original file and other pertinent details from the header of the spectrum file. Other data will be available in the overall directory.

Hopefully, if we can obtain the spectra and analysis from the counting laboratories in this calendar year(1992), then the archived spectra will be available during calendar year1993 for outside users. Then, scientists and engineers needing information concerning activation of spacecraft material in low-earth orbit will have a source of data that can greatly aid them in their individual projects.

REFERENCES

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8. Watts, J. W., Jr.: Predictions of LDEF Fluxes and Dose Due to Geometrically Trapped Protons and Electrons, Nucl. Tracks Radiat. Meas. 20, 85(1990).

Table 1. Counting Facilities
and Associated Scientists

Dr. Gerald Fishman
Dr. B. Alan Harmon
NASA/Marshall Space Flight Center(NASA/MSFC)

Dr. Ronald L. Brodzinski
Dr. James Reeves
Pacific Northwest Laboratory(PNWL)
Batelle Memorial Institute

Dr. Alan R. Smith
Donna L. Hurley
Lawrence Berkeley Laboratory(LBL)

Dr. Calvin E. Moss
Dr. Robert C. Reedy
Los Alamos National Laboratory(LANL)

Dr. David C. Camp
Lawrence Livermore National Laboratory(LLNL)

Mr. Charles Frederick
Tennessee Valley Authority(TVA)
Western Area Radiological Laboratory

Dr. David J. Lindstrom
NASA/Johnson Space Center(JSC)

Dr. Bill Winn
Westinghouse Corporation
Savannah River Laboratory(SRL)

Table 2. Sample Text File for Archived Gamma Ray Spectra

SPECTRUM FILE:1791NASA.PCA
SAMPLE COMPOSITION:ALUMINUM
START DATE:JAN 16, 1991
START TIME:10:23:00 am
REAL/CLOCK TIME: 254700 seconds
ELAPSED/LIVE TIME: 231216 seconds

CHANNEL	COUNTS							
1	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	21
25	133	141	136	132	136	122	131	127
33	145	132	125	121	117	146	103	117
41	104	100	98	114	102	95	116	127
49	138	118	123	117	122	99	109	106
57	105	104	106	98	115	117	96	108
65	103	99	101	119	87	91	89	97
73	105	107	102	102	90	90	90	81
81	114	94	100	103	87	103	101	122
89	109	106	90	96	101	123	102	79
97	88	93	84	95	92	93	87	76
105	115	88	92	123	112	88	106	94
113	112	88	91	103	99	91	112	105
121	107	93	109	95	105	113	164	207
129	195	149	82	90	100	98	88	99
137	116	102	101	120	124	97	101	102
145	122	101	127	126	106	125	164	190
153	136	113	139	170	155	133	100	130
161	112	107	102	112	113	108	114	127
169	137	138	186	165	160	123	125	148
177	178	136	125	127	131	124	111	119
185	122	215	374	369	245	153	121	107
193	98	113	108	108	98	107	122	118
201	126	96	110	109	110	113	131	91
209	123	105	115	120	117	123	119	111
217	114	115	107	117	119	132	115	130
225	133	124	130	142	121	135	124	107
233	110	130	125	120	108	119	116	121
241	112	131	121	134	132	108	124	134
249	128	116	113	131	123	133	129	136
257	153	118	139	125	126	144	133	107
265	132	136	140	123	126	131	129	130
273	121	140	123	149	133	136	140	122
281	121	137	152	138	137	166	106	148
289	139	166	184	189	160	140	133	152
297	135	156	154	125	144	141	128	136
305	136	143	131	152	148	124	179	158
313	164	138	154	161	159	153	126	139
321	146	146	161	154	137	167	139	138
329	155	134	186	172	177	143	168	162
337	148	148	134	172	147	178	158	157

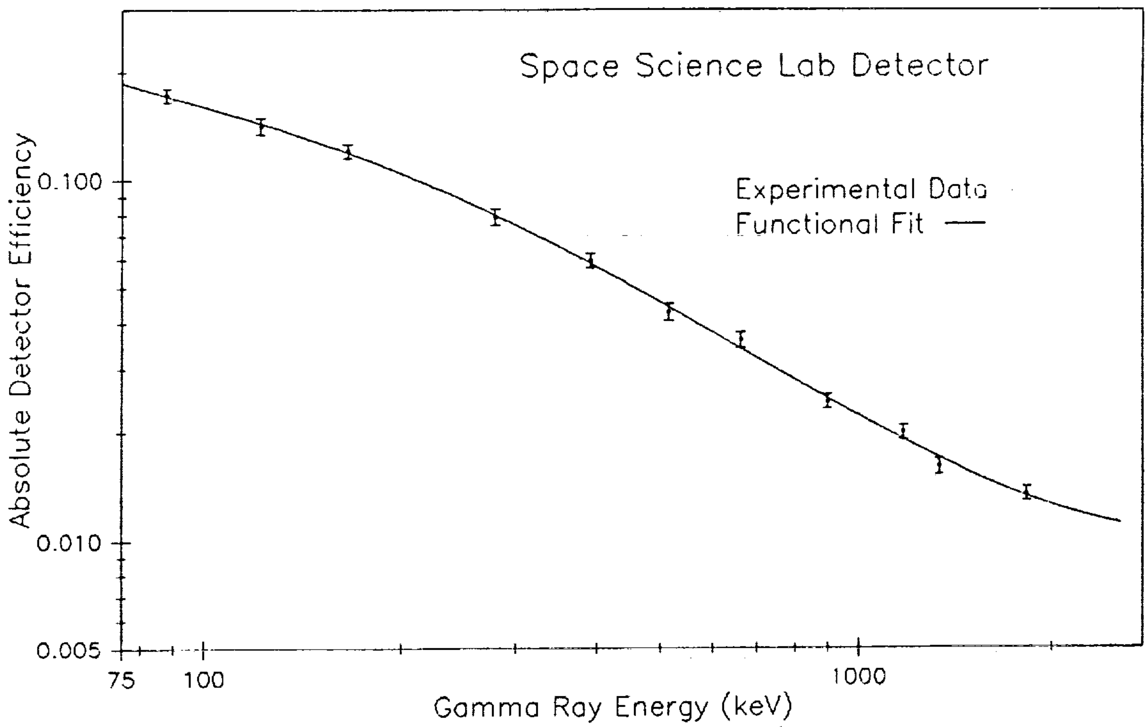

Figure 1. Efficiency Curve for SSL/MSFC Detector

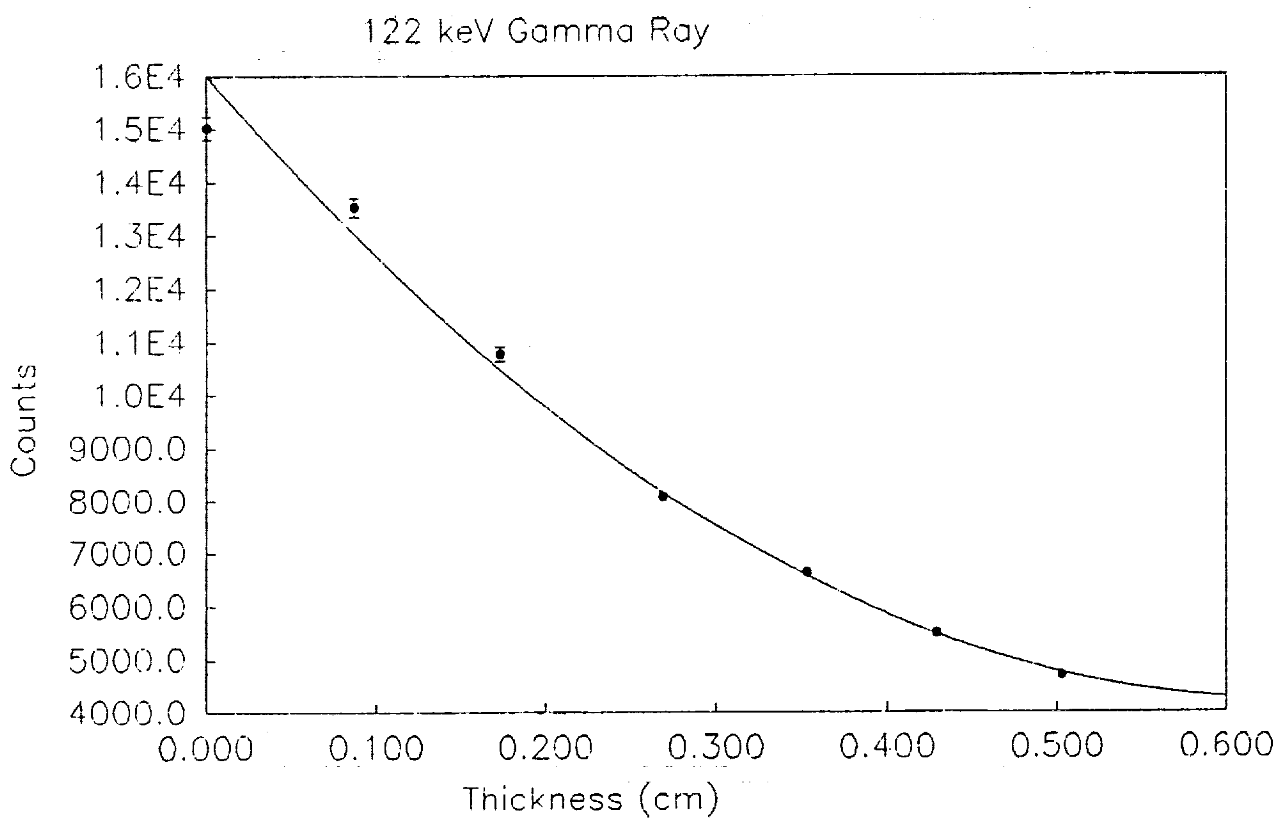

Figure 2. Yield of 122 keV Gamma Ray vs. EFFATN Prediction

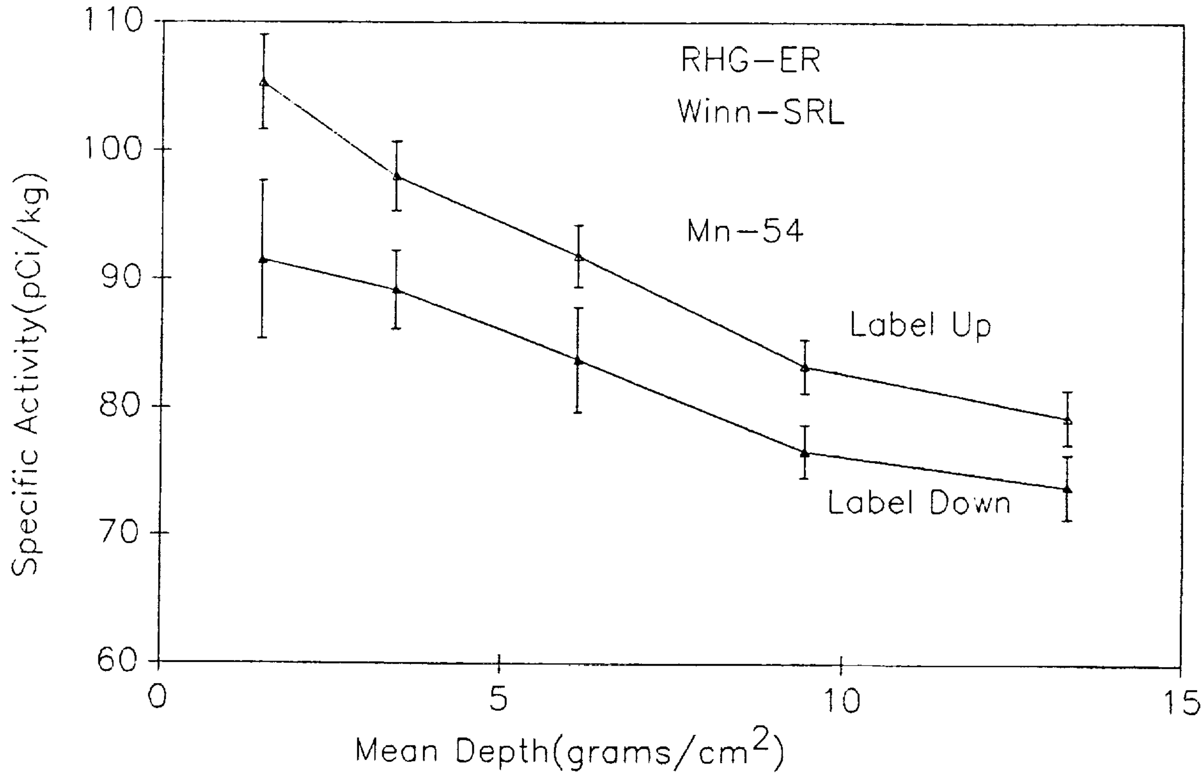

Figure 3. RHG Trunnion Layers(Earth End) Counted Face Up and Face Down.

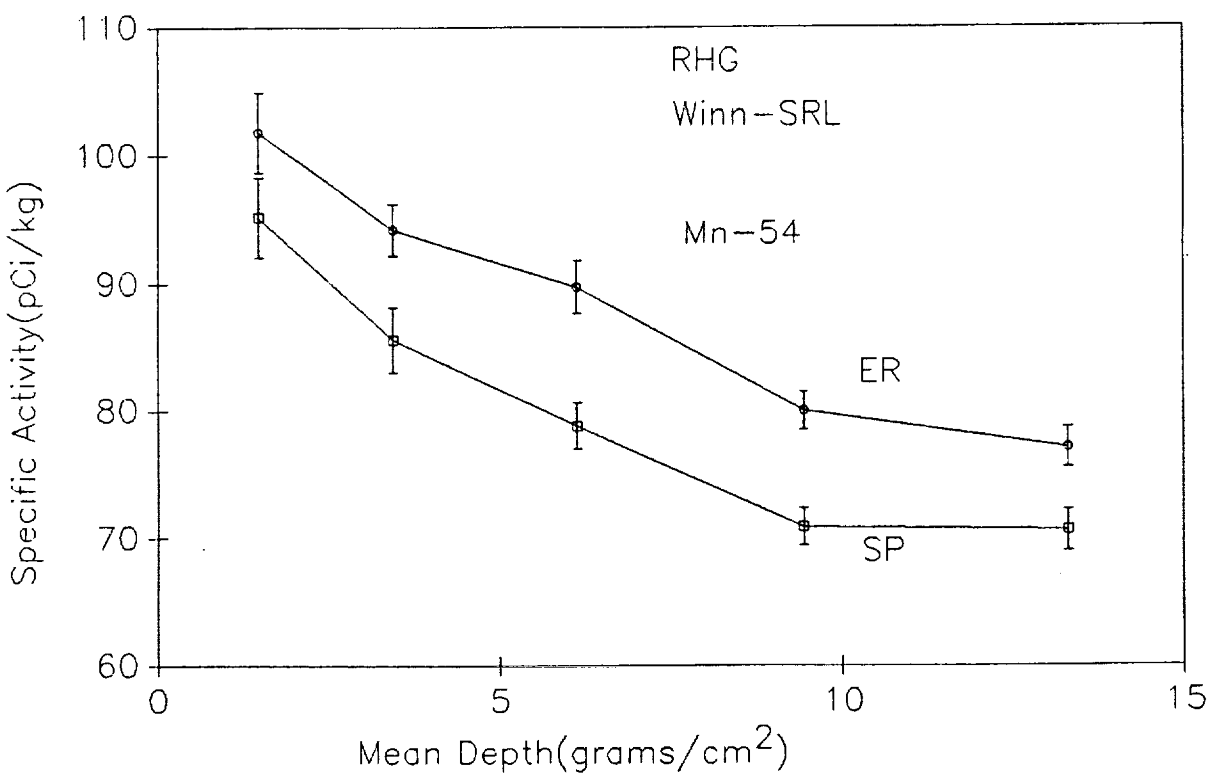

Figure 4. RHG Trunnion Layers: ER-Earth: SP-Space

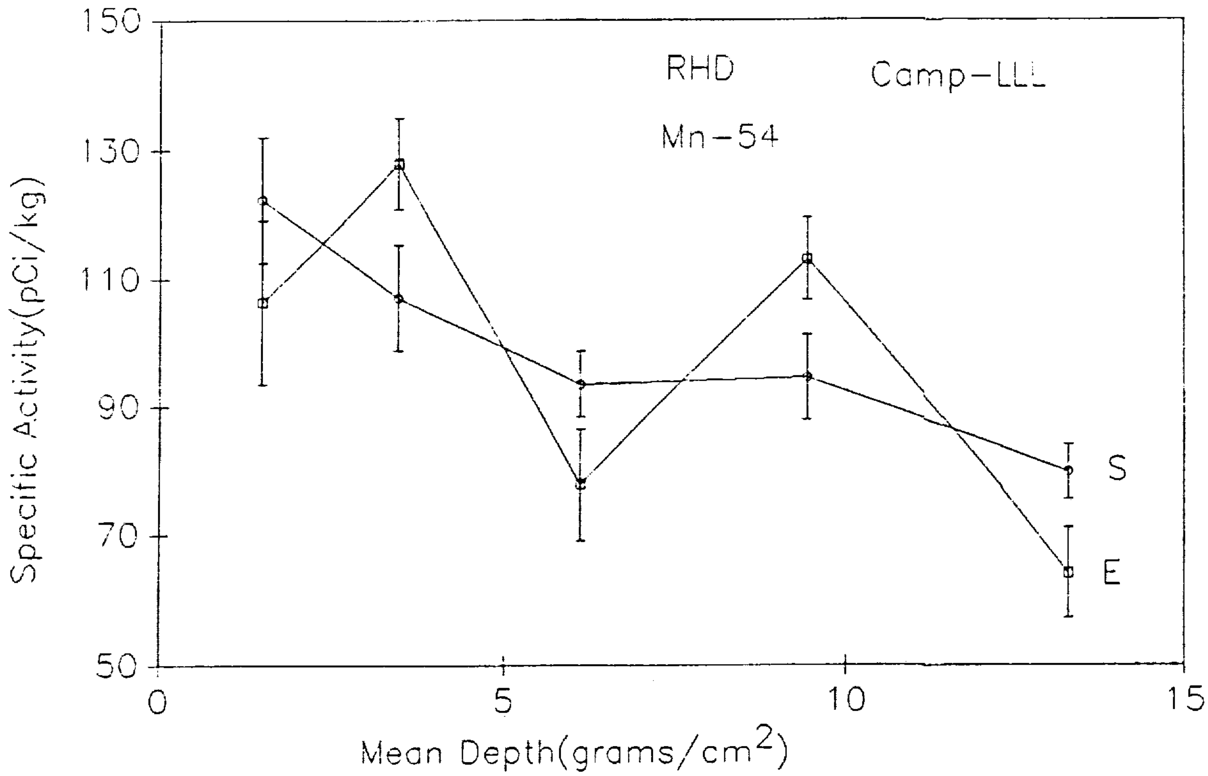

Figure 5. RHD Trunnion Layers: S-Space: E-Earth

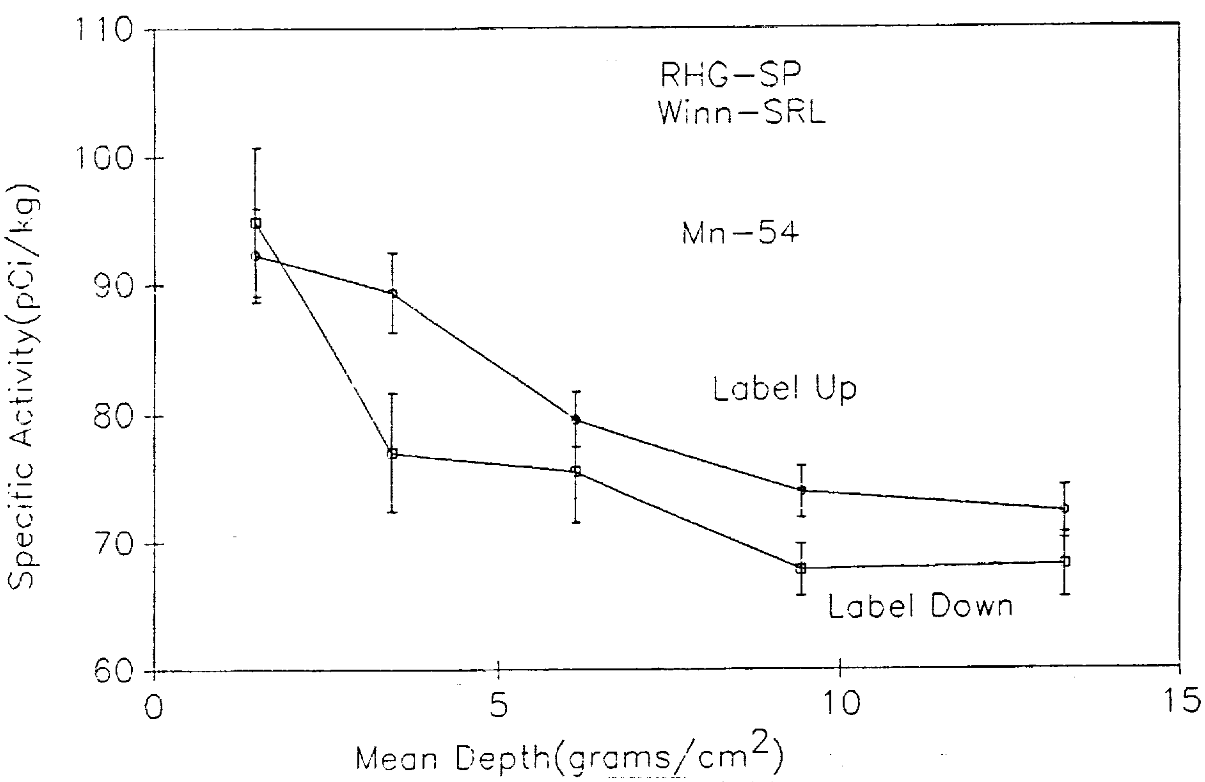

Figure 6. RHG Trunnion Layers-Space End.

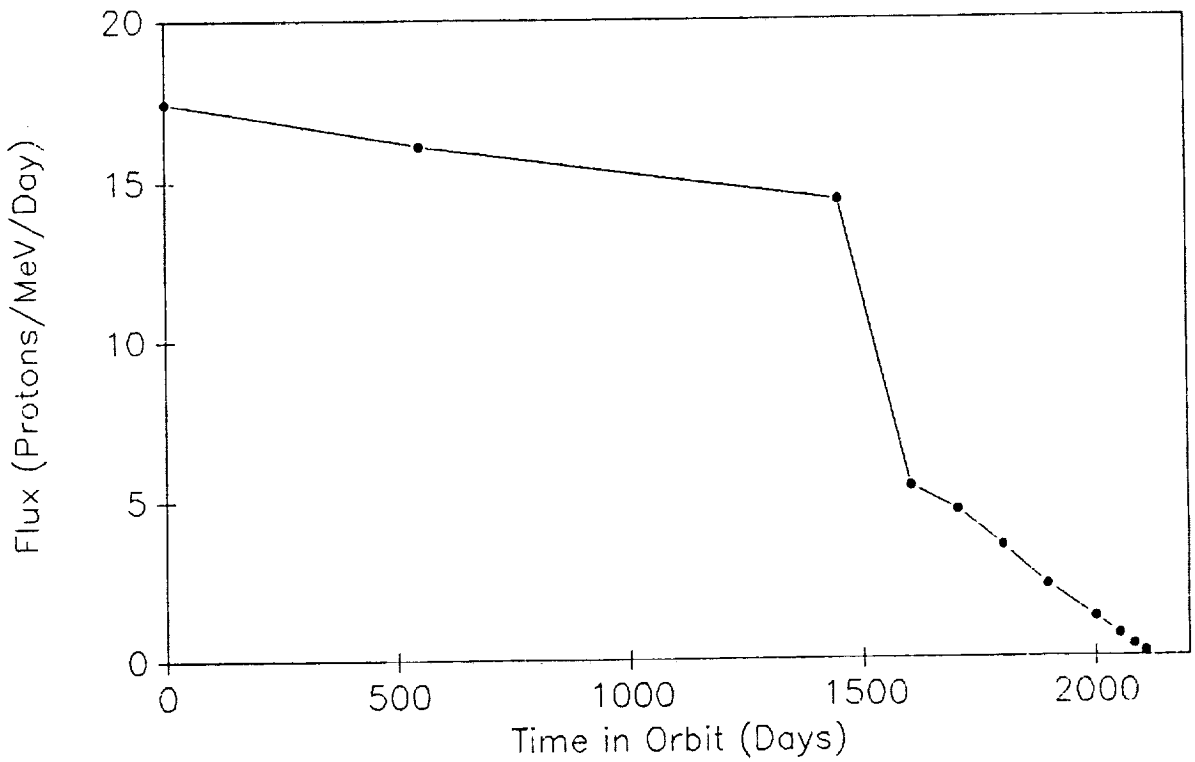

Figure 7. Proton Flux at 50 MeV as a Function of Time in Orbit

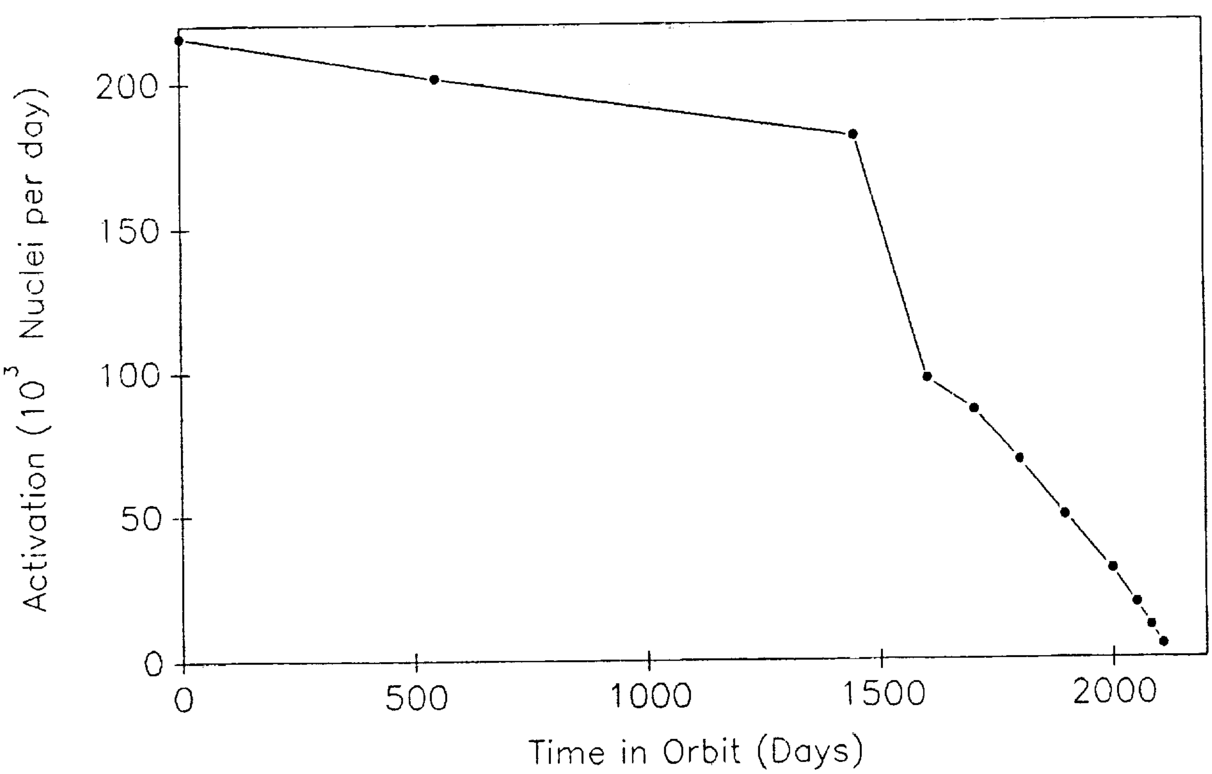

Figure 8. Production of Mn−54 as a Function of Time in Orbit

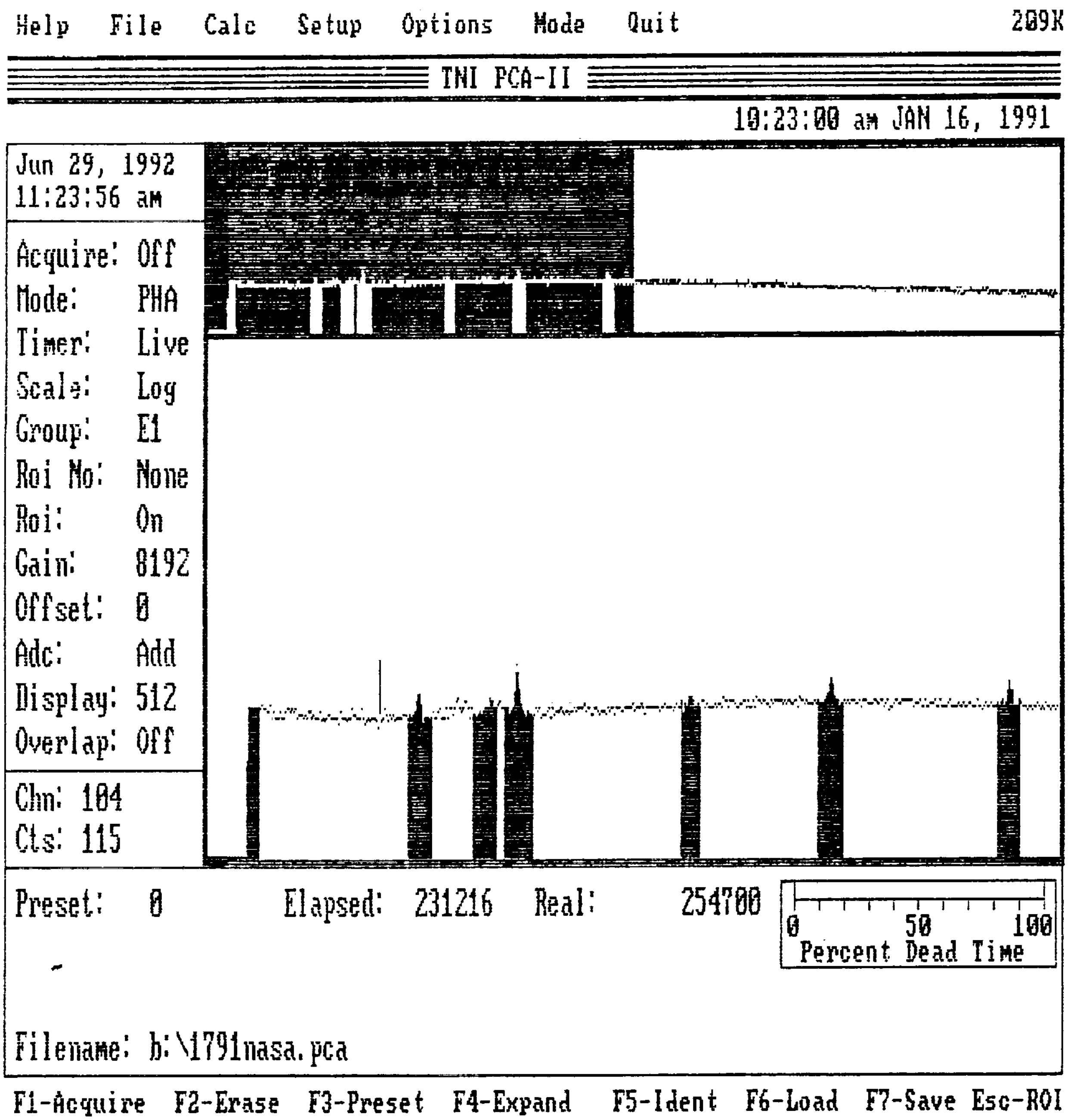

Figure 9. Sample of SRL Spectra converted to PCA-II Format.