View metadata, citation and similar papers at core.ac.uk
brought to you by CORE
provided by NASA Technical Reports Server

N92-23300

INDUCED RADIOACTIVITY IN LDEF COMPONENTS

B. A. Harmon
NASA Marshall Space Flight Center
Huntsville, AL 35812
Phone: 205/544-4924, Fax:205/544-7754

G. J. Fishman and T. A. Parnell
NASA Marshall Space Flight Center
Huntsville, AL 35812
Phone:205/544-7693, Fax:205/544-7754

C. E. Laird
Department of Physics
Eastern Kentucky University
Richmond, KY 40475
Phone:606/622-1526, Fax:606/622-1020

SUMMARY

A systematic study of the induced radioactivity of the Long Duration Exposure Facility (LDEF) is being carried out in order to gather information about the low earth orbit radiation environment and its effects on materials. The large mass of the LDEF spacecraft, its stabilized configuration, and long mission duration have presented an opportunity to determine space radiation-induced radioactivities with a precision not possible before. Data presented include preliminary activities for steel and aluminum structural samples, and activation subexperiment foils. Effects seen in the data show a clear indication of the trapped proton anisotropy in the South Atlantic Anomaly and suggest contributions from different sources of external radiation fluxes.

INTRODUCTION

A systematic study of induced radioactivity in materials carried aboard the Long Duration Exposure Facility has provided a significant and very useful database for space radiation-related applications. This study was broad-based to include as many different materials as could be obtained from the LDEF structure and experiments. In essence, the entire spacecraft was used as a passive detector to sample the radiation environment in low earth orbit.

The uniqueness of the LDEF spacecraft for radiation studies not only stems from its extended flight time (mission duration 5.8 years), but also its large mass and passively stabilized geometry. The stabilized configuration was designed to control exposure of various experiments to the space environment, and in particular, allowed directional aspects of the induced radioactivity to be studied on the leading (eastern), trailing, north and south sides of the spacecraft, as well as the earth and spaceward directions.

The induced radioactivity is produced by several sources of particle fluxes: galactic protons, trapped Van Allen protons (encountered in the South Atlantic Anomaly and accounting for the bulk of the activity), atmospheric and secondary neutrons, and to a small extent heavier ions. All of these particles induce radioactivity by colliding with a stable nuclide in the spacecraft material, and occasionally forming a radioactive nuclide. If its half-life is long enough, it can be detected in the laboratory following retrieval. The sources of external radiation flux, the nuclear reactions with the spacecraft material, and the spacecraft geometry can be combined, in principle, into a model to predict the experimentally measured activities. Such a comparison of calculation and experiment can be very useful for future long duration missions in low earth orbit (LEO), such as Space Station Freedom and the Earth Observing System, where accurate radiation dose predictions are required.

SAMPLE PROCESSING AND DISTRIBUTION

Following retrieval of the LDEF in January of 1990, samples for measurement of induced radioactivity were obtained from the Kennedy Space Center over a period of a few months. Some samples were obtained from the structural components of the spacecraft; others were taken from experiment trays under agreements with the experiment investigators. Approximately 400-500 samples were processed at the Marshall Space Flight Center and distributed to eight nationally recognized laboratories for analysis: Lawrence Berkeley Laboratory, Los Alamos National Laboratory, Johnson Space Center, Lawrence Livermore National Laboratory, Savannah River-Westinghouse, the Tennessee Valley Authority-Western Area Radiological Laboratory, Battelle-Northwest Laboratory, and the Marshall Space Flight Center.

High-purity germanium detectors are used to detect gamma rays from decaying radionuclides, and must be well-shielded from gamma rays produced by secondary emission from cosmic rays and naturally radioactive materials in the laboratory. Typical measured results are in the range of 0.1-100 picoCuries per kilogram of material in the LDEF spacecraft. Some radionuclide activities, as in the steel and aluminum structural components, were strong enough to allow mapping of their directional and depth-dependent characteristics.

Figure 1 shows the positions of various materials on the LDEF spacecraft that were analyzed for induced radioactivity. The steel trunnions (alloy 17-4PH) from the end support frame (Earth end) of the LDEF were the first components acquired for analysis. Other structural materials obtained later included aluminum experiment tray clamp plates and trunnion clamp assemblies, titanium structural clips, and lead ballast plates. An activation subexperiment consisting of metal foils (ref. 1) was also included in several experiment trays. These included sets of five different metals (cobalt, vanadium, tantalum, indium and nickel). These were chosen because of their simple isotopic makeup and significant long-lived radionuclide production. In addition some samples were obtained by agreement from other experimenters, such as magnesium, copper, germanium, niobium, silver, and teflon. Many of these samples, however, were not of sufficient mass to yield good signal-to-background ratios for accurate measurement.

PRELIMINARY RESULTS

In this section, preliminary results obtained in the analysis of LDEF induced radioactivity are presented. Absolute activities have been corrected for decay since retrieval and for detection geometry, and are estimated to be good to 20%.

A detailed representation of the west trunnion (adjacent to experiment tray row 3 in figure 1) with respect to the external environment and the pattern in which samples were prepared from it is shown in figure 2. Samples were cut in 1.3, 1.9 and 2.5 cm- (0.5, .75 and 1 in) thick cylindrical sections 8.3 cm (3.25 in) in diameter for bulk activity measurements, and thinner 5 cm (2 in) square layers of varying thickness to study depth and directional dependences.

Examples of spectra showing peaks from gamma-decaying radionuclides produced in the end section (section A in figure 2) in each of the two steel trunnions are shown in figure 3. These two samples were activated primarily by the trapped proton flux from (a) the east (onto the leading side of the spacecraft) and (b) the west (onto the trailing side of the spacecraft), respectively. These spectra indicate production of ^{56}Co, ^{58}Co, ^{54}Mn and ^{46}Sc with half-lives ranging from 71 to 312 days. An enhancement of the intensity of 835 keV ^{54}Mn peak by a factor of ~2 in the west-facing sample relative to the east-facing sample can clearly be seen. This effect is caused by the interaction of the trapped protons in the South Atlantic Anomaly with upper atmospheric gases. In the SAA the flux encountered by the leading (east) side of the spacecraft is attenuated relative to the trailing (west) side flux because the east side flux is traveling about a magnetic field line below the spacecraft, and thus penetrates deeper into the atmosphere. This effect has been quantified recently by Watts, et al. (ref. 2) and is being incorporated into the radiation models being developed currently. The 478 keV line observed on the leading side of the spacecraft (top figure) was determined to be caused by a deposition of atmospheric ^{7}Be on the surface of the spacecraft, and was not produced by spallation within the spacecraft material (ref. 3) (See also J. C. Gregory, et al., these conference proceedings).

Figure 4 illustrates the effect of the anisotropic SAA flux, where the west/east ratio of the ^{54}Mn activities as a function of distance is plotted along the axis of the trunnion. The difference in activity from one side to the other decreases with depth due to attenuation of the proton flux, even though the anisotropy of the external flux is known to increase with energy. The majority of the SAA protons which activate the steel are in the range of 20-120 MeV, and are stopped in the first 2 cm (0.8 or 15 g/cm^2) of material. The bulk activity for ^{54}Mn in the trunnion interior does not drop to zero, however, but reaches approximately 80 picoCuries/kg (see C. E. Moss and R. C. Reedy;

W. G. Winn, these conference proceedings), which may be caused by secondary activation by neutrons as well as high energy background fluxes of cosmic ray protons in the energy range of several GeV. These contributions are currently being included in a simplified three-dimensional spacecraft mass model (See B. L. Colborn and T. W. Armstrong, these conference proceedings).

A large number of aluminum experiment tray clamps (alloy 6061-T6) were obtained from the LDEF following deintegration of the spacecraft. The clamps were approximately 5 cm (2 in) by 12.7 cm (5 in) and 0.47 cm thick (.185 in or 1.3 g/cm^2). A total of 50 clamps have been counted at the TVA Western Area Radiological Laboratory to investigate the variation of activating flux with direction. Clamps were obtained from the spacecraft on each row to allow measurement of the change in flux every 15 degrees. In figure 5, the ^{22}Na activity based on the 1275 keV line is shown as a function of angle from the leading direction of the spacecraft (east). A comparative one-dimensional calculation is also shown (see T. W. Armstrong and B. L. Colborn, these conference proceedings.) based on the proton anisotropy model (ref. 2) normalized to AP8 omnidirectional flux, and measured cross sections for protons on aluminum, which is within 30% agreement with the measured activation. The peak of the ^{22}Na activity in the trailing side plates is clearly apparent.

The activation subexperiment foils of vanadium, cobalt, indium, tantalum and nickel were analyzed as they were obtained from LDEF experiments M0001, M0002, P0006, and A0114. The results for each of the four nickel samples counted at Marshall Space Flight Center are shown in figure 6 along with predictions of a one-dimensional calculation with the AP8 flux for proton activation of the 5 cm (2 in) square by 0.32 cm (.125 in) thick nickel foils. The upper and lower limits of the calculation represent the range of proton-induced activation caused by (a) normally incident flux on the nickel surface, (b) a uniform exposure in all directions, and (c), same as (a) and (b) but shielded by 1 cm (0.4 in) of aluminum. These calculations represent the range of shielding/flux conditions to which the nickel samples were exposed around the spacecraft. By modeling the local geometry of these samples, it may be possible to separate shielding effects from contributions due to different activation sources. For example, the small amount of ^{60}Co observed in these samples can be produced alternately by an (n,p) reaction on ^{60}Ni (abundance 26.1%) above 5 MeV, or proton reactions on the other stable isotopes of nickel (^{61}Ni, ^{62}Ni and ^{64}Ni, total abundance 5.6%). More refined calculations may be able to distinquish these two contributions. Further analyses of the nickel samples and the indium cobalt, tantalum, and vanadium samples are in progress.

ANALYSIS PLAN/CONCLUSION

Most of the low level counting has now been completed and the effort has shifted to collection and analysis of data from the counting laboratories. Much of the analysis and archiving of these data will be performed at Eastern Kentucky University to produce a large database of the measured induced radioactivities. The current scope of this effort is to be able to provide specific activities for different materials whenever the detection geometry is reasonably convenient for normalization of the gamma ray counting measurements. In other cases, where only relative measurements were possible, information about depth and directional dependences can still be extracted.

Measurements and analyses of the induced radioactivity in the Long Duration Exposure Facility will continue through 1991. Detailed plans can be found in the Long Duration Exposure Induced Radioactivity Analysis Plan (ref. 4). A program of calculations in order to extract as much information as possible about various sources of radioactivity is now underway (See T. W. Armstrong and B. L. Colborn, these conference proceedings.). It is hoped that these studies will yield a complete and accurate picture of the low earth orbit radiation environment.

REFERENCES

1. Clark L. G.; Kinard, W. H.; Carter, D. J.; and Jones, J. L.: The Long Duration Exposure Facility Mission 1 Experiments. NASA SP-473, 1984, pp. 1-189.

2. Watts, J. W.; Parnell, T. A.; and Heckman, H. H.: Approximate Angular Distribution and Spectral for Geomagnetically Trapped Protons in Low-Earth Orbit. AIP Conference Proceedings 186, 1989, pp. 75-85.

3. Fishman, G. J.; Harmon, B. A.; Parnell, T. A.; Gregory, J. C.; Peters, P.; Haskins, P. S.; McKisson, J. E.; Ely, D. W.; Weisenberger, A. G.; Piercy, R. B.; Phillips, G. W.; King, S. W.; August, R. A.; Ritter, J. C.; and Cutchin, J. H.: Observation of ^{7}Be on the Surface of the LDEF SPacecraft, Nature 349, 1991, pp. 678-680.

4. Fishman, G. J.; Parnell, T. A.; and Harmon, B. A.: Long Duration Exposure Facility (LDEF) Induced Radioactivity Analysis Plan, NASA TM-103545, 1991, pp. 1-32.

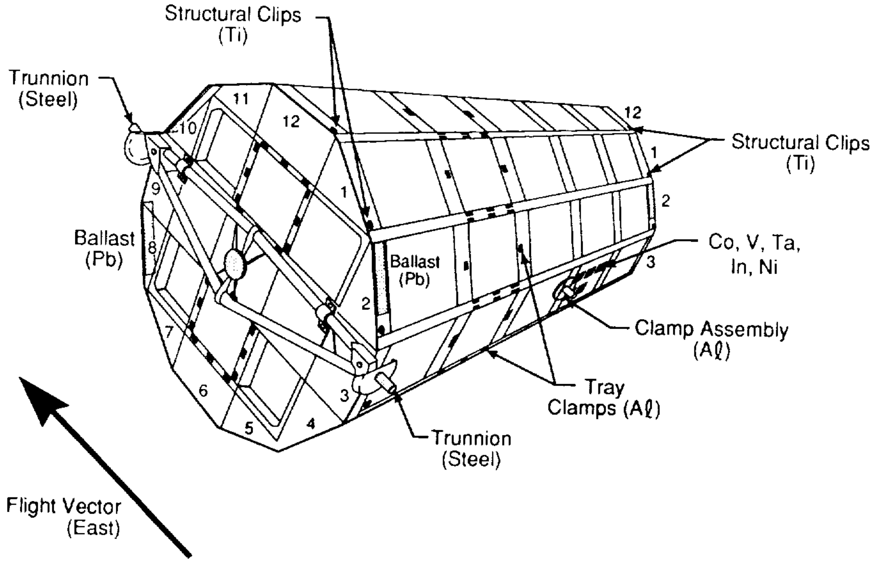
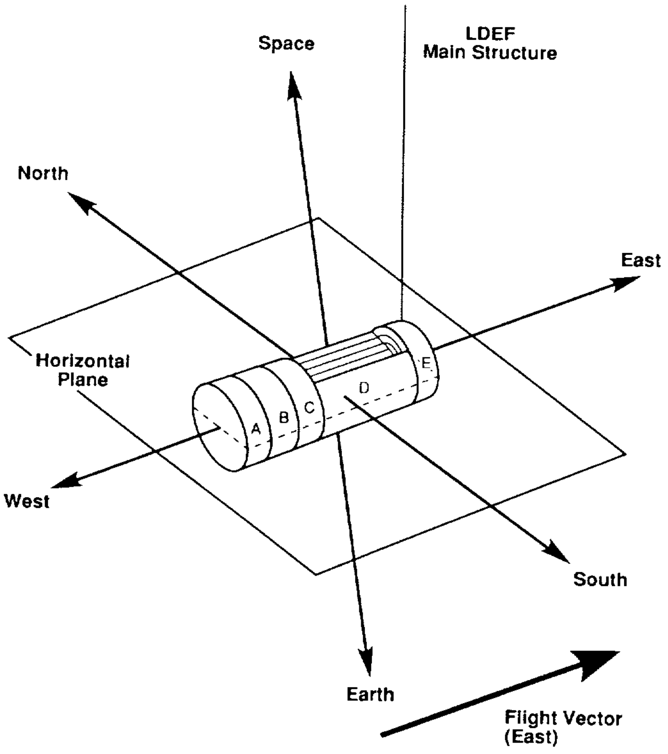


Figure 1



West (Trailing) Trunnion Orientation

Figure 2

LDEF Acquired Activity

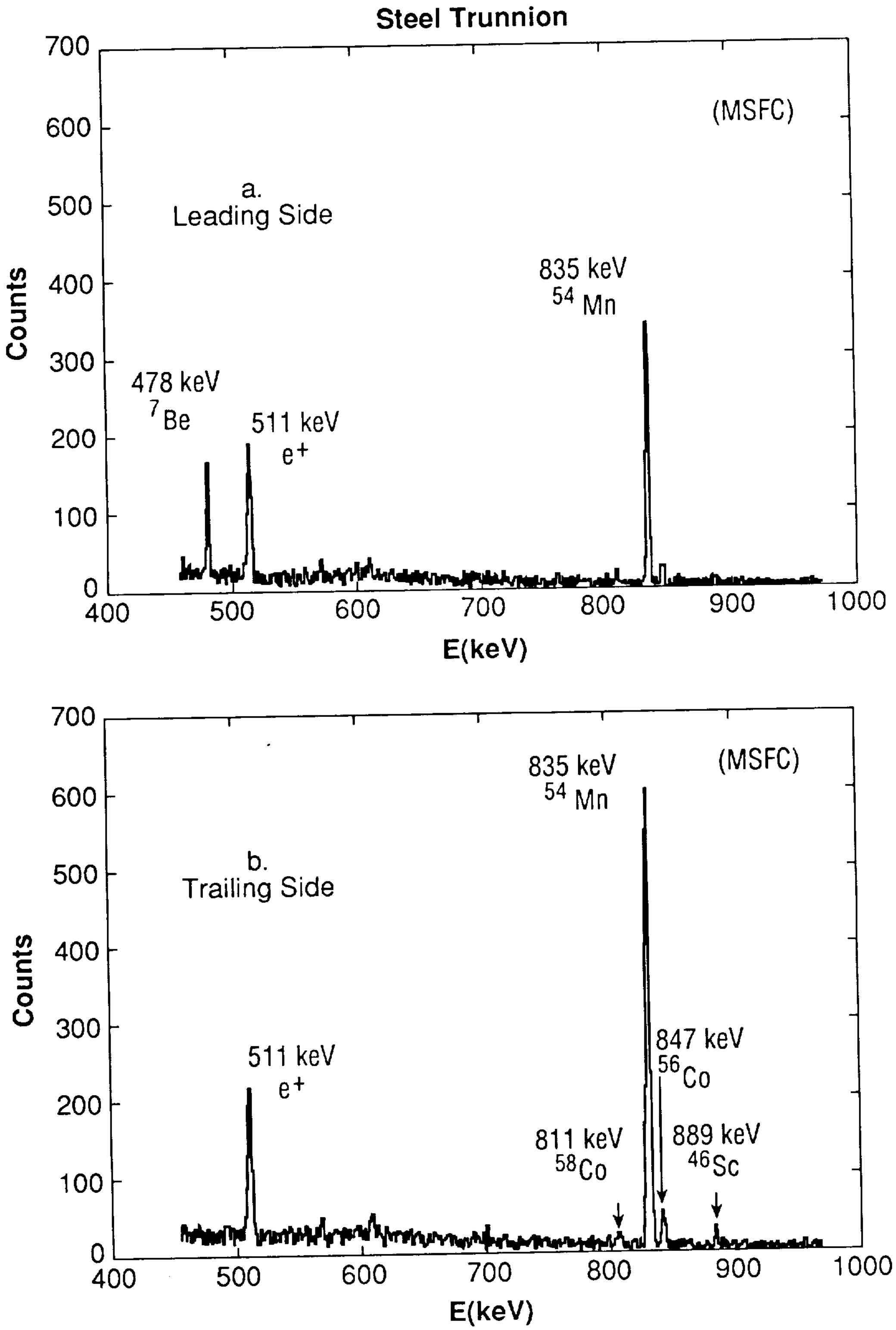


Figure 3

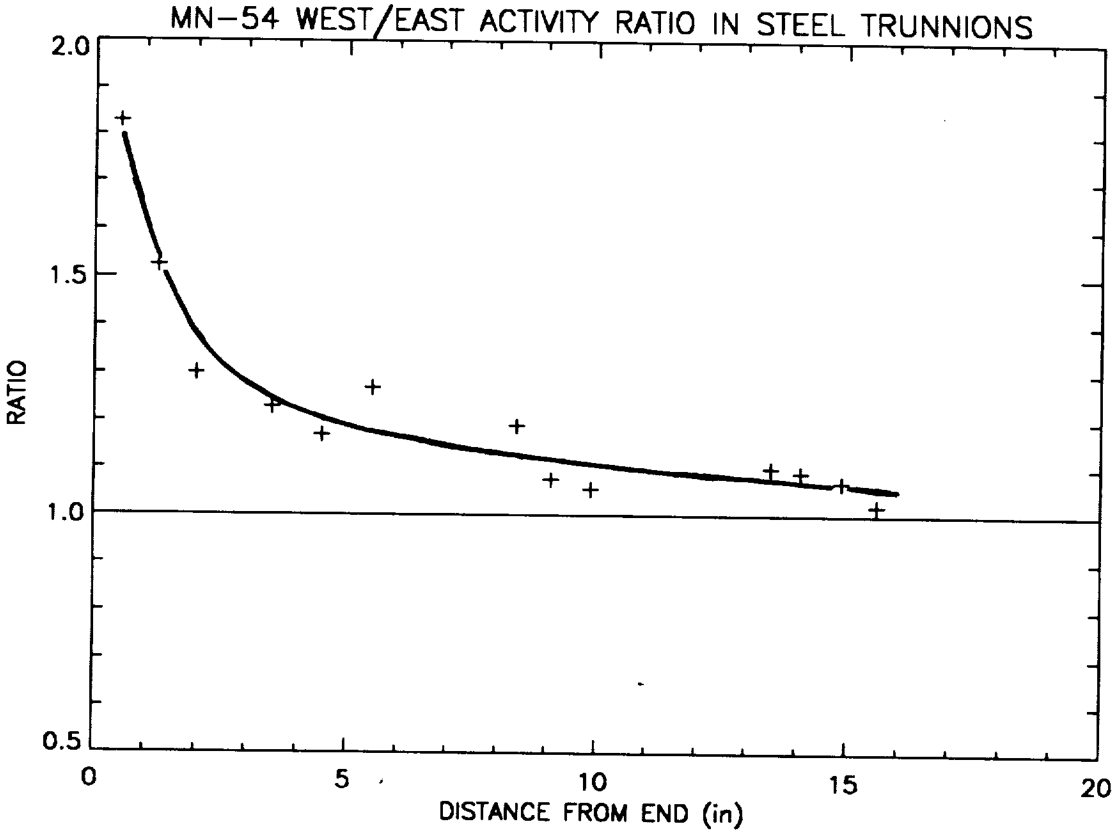


Figure 4

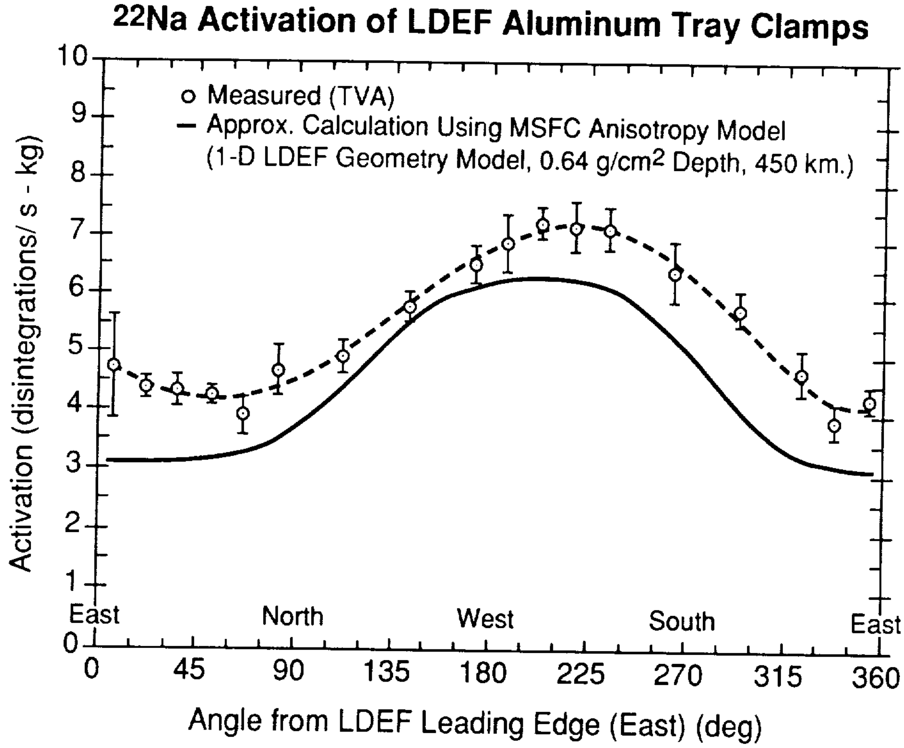


Figure 5

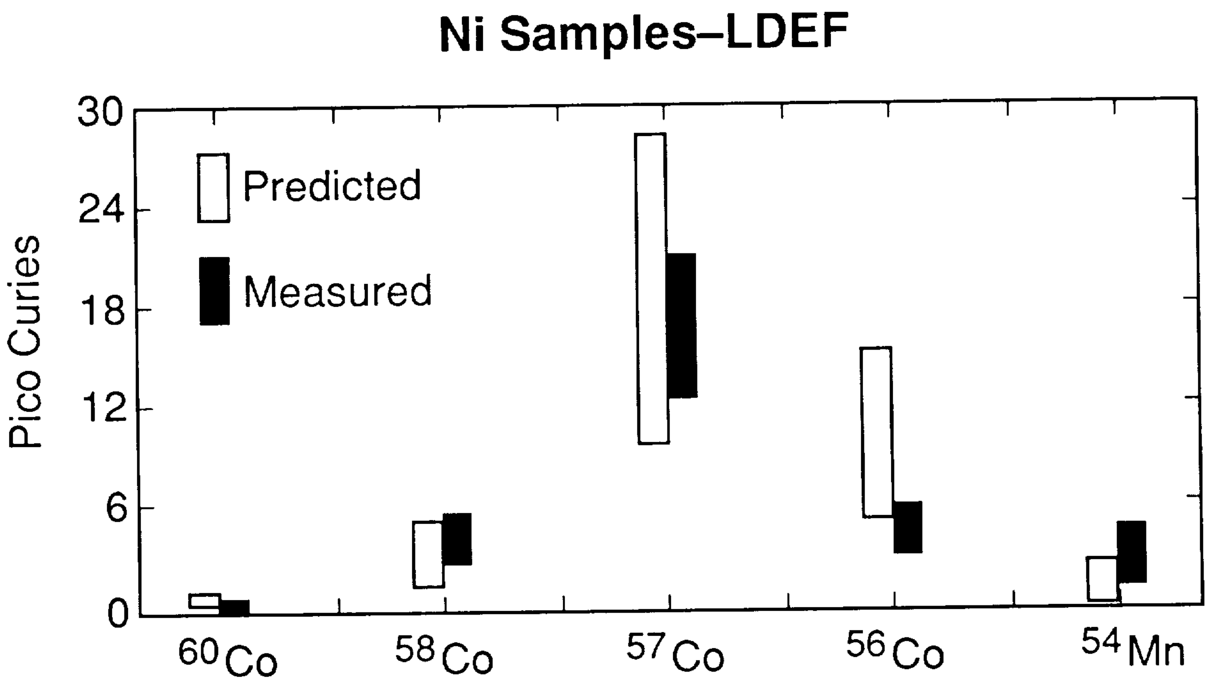

Ni Samples–LDEF
Predicted
Measured
Pico Curies
0
6
12
18
24
30
^{60}Co
^{58}Co
^{57}Co
^{56}Co
^{54}Mn

Figure 6