A PHOTON PHREAK DIGS THE LDEF HAPPENING

Alan R. Smith and Donna L. Hurley
Engineering Division
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720
Phone (510) 486-5679 FAX (510) 486-5888

ABSTRACT

A year ago at the First LDEF Post-Retrieval Symposium, we reported detailed measurements on trunnion sections, as well as results from "intentional" samples (Co, Ni, In, Ta, and V) and spacecraft parts. For this year's Symposium we re-evaluate some of these findings in combination with more recent results, to cast a longer perspective on the LDEF experience, and to sketch some promising avenues toward more effective participation in future missions. The LDEF analysis effort has been a superb training exercise, from which lessons learned need to be applied to future missions - - right back to the early phases of mission planning.

INTRODUCTION

A dedicated group of experts in low-level gamma-ray spectrometry has worked diligently at a number of laboratories across the USA, to produce an impressive array of radiometric analyses on LDEF samples and spacecraft parts (refs. 1, 2). This effort was most intensive during the first few months of sample availability: the period March - August 1990.The LBL measurement program continued into calendar 1991 and 1992 at a reduced pace, and there remain selected samples to be counted for the first time at the Oroville Facility when our new "Merlin" detector arrives; these are samples that require long counting times in a very low-background environment. In addition, it may be worthwhile to re-examine some samples containing long-lived radionuclides in order to achieve higher precision, for example: the LDEF aluminum clamp plates, to produce more accurate Na-22 activity values for detailed comparison with model predictions.

It is a rare privilege, this participation in the LDEF analysis program, and we look forward to continuing with future LDEF sample analysis. We are in the midst of a major upgrading of the LBL Low Background Facilities, a process that has been strongly stimulated by our LDEF participation; consequently, we will be in a position to offer greatly expanded analysis capability to future space missions, be they of days-long or years-long duration.

In the following sections of this report we illustrate how our LDEF analysis efforts have led to recommendations for revising some procedures in order to enhance the value of radiometric analysis results from future missions. We also describe extensions of this technology which have the potential to provide useful data in the quest to understand the recent history of solar activity.

SAMPLE SIZE: BIGGER CAN BE MUCH BETTER

Results of our measurements of the North-to-South profile for Mn-54 activity in trunnion section LHG are shown on Table I. Also listed are the ranges of observed count rates in the 834 KeV peak, count times, and individual sample weights. Our aim was to produce data of good statistical quality (no greater than 3% standard deviation) so that small changes in profile shape could be identified, for example: the possible appearance of a broad "peak" in Mn-54 activity in the core region of the trunnion that would be associated with the buildup of secondaries generated by galactic cosmic ray interactions.

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TABLE I

Profile of Mn-54 Activity vs depth in Trunnion Section LHG

Trunnion Slice		Mn-54 pCi/Kg	Mn-54 S.D.
LHG	N1	171.3	6.0
	N2	137.3	5.2
	N3	117.5	3.7
	N4	105.1	2.0
	N5	95.0	2.5
	N6	93.1	3.8
	N7	97.0	3.2
	Core		
	S7	82.6	2.6
	S6	73.4	2.8
	S5	69.3	2.1
	S4	68.4	2.8
	S3	75.8	2.4
	S2	88.2	2.7
	S1	107.3	4.7

Parameter Ranges

Count Rates:
0.074-0.470 c/min

Count Times:
2400-10100 min

Sample Weights:
30-70 grams

Although we generally achieved the goal of 3% statistical precision, some counting times of 10000 minutes (7 days) were required for these relatively small samples. Week-long count times severely constrain the number of samples that can be analyzed - -even when the facility is "dedicated" and the halflives are suitably long. Shorter counting times become imperative, when considering the need to measure short halflife isotopes that would dominate from shorter (days to weeks-long) Space Shuttle missions.

We are implementing significant improvement in this aspect at the LBL/ORO Facility, where an upgrade replacement for our "Merlin" detector will soon be in operation, providing an approximate 3-fold increase in detection efficiency. We expect count time reductions of a comparable factor without any sacrifice in measurement precision. Conversely, keeping to the long count times would enhance measurement precision for some of the nuclides which produced much smaller peaks in these trunnion samples, such as: Co-56, Co-57, Co-58, Co-60, Ti-44, and Na-22.

Further improvement in our ability to measure such minute activities can most reasonably come through an increase in sample size. Suppose the typical 50-gram sample is increased in weight to 1 Kg, a 20-fold increase. If the resultant peak count rates increased only half this ratio, we would achieve a 10-fold gain. Combining the gain in efficiency with this sample-size gain produces a 30-fold reduction in count time, while maintaining the original precision. A week-long count becomes a 6-hour count. That is progress!

This effect can be seen from the previously cited results for single trunnion slices, compared to a special "Merlin" run on a collection of these same samples. A group of 18 trunnion slices was arranged around the sides and at the end (standard position) of the detector endcap. Total sample weight was about 1 Kg, from which the week-long run produced a Mn-54 activity value with 1% standard deviation. A small portion of this spectral data is plotted on Fig. 1, where the feature of greatest interest is the prominent peak at 1274 KeV belonging to Na-22, measured here to a precision of about 10% This peak was either unobservable or so small as to be quantitatively useless in all data obtained from week-long

runs on single slices. The presence of Na-22 in these stainless steel samples signifies a reaction requiring an incident particle energy in the low hundreds of MeV, representing the highest-energy reaction documented in LDEF materials through observation of induced-activity radionuclides.

A short portion of the spectrum from a Pb ballast slice is displayed on Fig 2, which shows the presence of 38-year halflife Bi-207, which was produced mainly by a proton-specific reaction on Pb. This data was obtained in a week-long "Merlin" run on a 2"x2"x1/8" thick Pb sample. While the peak is small, it is quantitatively useful (about 10% S.D.), and could be much more easily and accurately assayed upon implementation of the previously described system improvements.

WHAT TO SHOOT AT: SELECTION OF TARGET MATERIALS

Target materials (elements) must be carefully selected to provide as much information about the radiation field as possible. The nuclear reaction products (induced-radioactivities) discussed here can all be assayed by gamma-ray spectrometry, the most convenient method for direct measurement on "thick" samples. Our emphasis is on radionuclides with halflives long enough to be suitable for monitoring missions of many months to years duration, but at the same time noting that there are nuclides with shorter halflives appropriate for similar monitoring functions on short duration missions.

It is desirable, but not necessary, that target elements are of the single stable isotope category, such as Be, Na, Al, V, Mn, Co, Nb, I, Ta, Au, and Bi. Also acceptable are elements in which one stable isotope dominates, such as B, C, O, Si, S, and Fe. Similarly acceptable are elements in which closely adjacent (one or two nucleons apart) isotopes are the dominant members, such as Cl, Ni, Cu, Zn, Ag, and Eu. In some cases elements with many stable isotopes may be selected because of certain important reactions, such as: Ti, for 47-year Ti-44; and Pb, for 38-year Bi-207. It is important to keep in mind that as the reaction product is further removed from the target element (more nucleons removed, which signifies higher threshold energies and multiple reaction paths) it becomes less important to start from a single-isotope target element.

A special category of target materials includes those elements which are major constituents of large-mass active detectors, such as: the inorganic scintillators NaI, CsI, and "BGO" (Bi and Ge), plastic scintillators (C), and the semiconductor detectors Si and Ge. Some induced-activity radionuclides (electron-capture decay) can be assayed internally by these detectors, others, by beta-gamma coincidence techniques involving the use of external detectors for the gamma-ray analysis.

A sampling of candidate radionuclides is given on Table II, which lists halflives along with prominent gamma-rays, and the materials in which some of these nuclides were detected in our LDEF samples. Neither target elements nor reaction paths are specified here, except that nuclides followed by an asterisk are slow-neutron capture products from adjacent high-abundance stable isotopes of the same element. Most of the rest are products of reactions requiring tens to hundreds of MeV incident particle energies, and can be initiated by either protons or neutrons or heavier particles.

There are a number of radionuclides with suitable halflives from which fluorescent X-rays are the only photons emitted at decay. These X-rays are of low energy, for example: the 5.9 KeV K-shell X-rays from decay of 2.7 year halflife Fe-55; they cannot be detected with reasonable efficiency from the "thick" samples upon which our gamma-ray technique is based. Consequently, no members of this class appear on Table II.

TABLE II

Some Medium Halflife Gamma-Emitters For Space Monitoring

Nuclide	Half-life Years	Prominent Gamma-rays	In LDEF Samples
Na-22	2.60	511,1274	Al,ss
Al- 26	7.2 E05	511,1809	
Ar- 42 (K-42)	33.	1525	
Ti- 44 (Sc-44)	47.	68,78,511,1157	Ti,ss
Mn-54	0.85	834	Co,Ni,ss
Co- 57	0.74	122	Co,Ni,ss
Fe- 60 (Co-60)	3.0 E05	1173,1332	
Co- 60 *	5.27	1173,1332	Co,Ni,ss,In
Zn-65 *	0.67	1116	
Kr-81	2.1 E05	276	
Nb-92	3.2 E07	560,934	
Nb-94 *	2.0 E04	703,871	
Tc-98	4.2 E06	652,745	
Rh-101	3.3	127,198	In
Rh-102	2.9	475,631,697	In
Ru-106 (Rh-106)	1.0	512,622	
Ag-108m *	127.	434,614,722	
Cd-109 *	1.2	88	
Ag-110m *	0.69	658,885,1384	In
Sb-125	2.7	428,600,636	
Sn-126 (Sb-126)	1.0 E05	415,666,695	
I-129	1.6 E07	40	
Ba-133	10.7	81,356	
Cs-134 *	2.06	605,796	
Cs-137 (Ba-137)	30.2	662	
Pm-143	0.73	742	
Ce-144 (Pr-144)	0.78	134,2185	
Pm-144	0.96	477,618,696	
Pm-146	5.5	454,736,747	
Pm-147	2.6	121	
Eu-150	36.	334,439,584	
Eu-152 *	13.3	122,344,1408	
Eu-154 *	8.5	123,723,1274	
Tb-158	150.	944,962	
Hf-172 (Lu-172)	1.87	181,810,1093	Ta
Lu-173	1.37	272	Ta
Hf-182 (Ta-182)	9.0 E06	68,1121,1221	Ta
Os-194 (Ir-194)	6.0	328	
Hg-194 (Au-194)	520.	328,1924,2044	
Pb-202 (Tl-202)	3.0 E05	440	
Bi-207	38.	570,1063,1770	Pb
Bi-208	3.7 E05	2614	

Measurement of the same isotope in a sequence of successively heavier target elements provides information about increasingly higher-energy components of the radiation field. For example, the reactions to produce Na-22 from Al, Si, S, Ti, and Fe have increasing energy thresholds ranging from a few tens of MeV up to a few hundreds of Mev. Reactions to produce 47-year halflife Ti-44 from Ti, Mn, Zn, and Ge encompasses a similar range of threshold energies. Suites of target elements that produce appropriately "short" halflife radionuclides can also be found to provide a similar range of energy spectral information from short missions. In either case, the enhanced system performance and increased sample size discussed earlier will be required if we are to extract the best quality radiometric information from returned samples.

A number of nuclides listed on Table II were not observed in our LDEF samples, but are attractive candidates in certain target elements were they placed aboard future missions; alternatively, some of these nuclides should be sought in machinery left on the lunar surface during the Apollo Program, when key parts of these items are returned to earth for their 30-year checkup. A valuable companion study should be done on key parts of long-dormant earth-orbit satellites - - retrievable during shuttle missions. Relevant materials include Al, Si, Ti, Fe, and any heavier elements such as Ag, Ta, W, and Pb - - provided they are available in large enough quantities.

HOW TO DO IT BETTER NEXT TIME

The radiometric sample analysis effort has identified a number of mission parameters that need revision if our performance is to be improved on future missions. Crucial among these is the time elapsed between spacecraft touchdown and sample availability. For "intentional" samples on short missions (days to weeks) this delay should be no more than a few hours. For example, from a shuttle landed at Edwards Air Force Base, counting at LBL could start within 6 hours if air transport is involved in shipment to Berkeley or Oroville, or within 10 to 12 hours if only surface transport is available. These brief delay times are essential to maximize the return from short-halflife (days to weeks) radionuclides - - the species most favorable for measurement from comparably short missions. Longer delay times might be appropriate for "intentional" samples from long missions, although longer than a week seems unnecessary. The availability of spacecraft pieces is a different matter, wherein considerably longer delays may be unavoidable. This circumstance is in itself a strong argument for inclusion of more "intentional" samples on future missions.

Sample size is also an extremely important parameter in determining the success of any gamma-spectrometry analysis effort, as we have already discussed. We mention again that increasing a sample from a typical 50-gram weight to a 1000-gram weight in "favorable" counting geometry should produce at least a 10-fold increase in peak count rates for most gamma-ray energies in most target materials. While recognizing the dramatic penalty paid to put additional weight into orbit, the few extra kilograms inferred here is a very small increment compared to the total weight of the Space Shuttle launch vehicle, the LDEF itself, or other large satellites.

Target materials (elements) for "intentional" samples must be carefully chosen, so as to maximize the information recovered from measurement of induced-activity radionuclides, as already mentioned. We note here that at least the elements Be, C, F, Na, Al, S, Si, Ca, Ti, Mn, Fe, Cu, Ge, Zr, Nb, Mo, Ag, Eu, W, Au, Pb and Bi should be considered as candidate "intentional" sample materials in addition to the LDEF suite (V, Co, Ni, In, Ta); further, that some elements from this list might be appropriate substitutes for the V and In samples that were aboard the LDEF satellite.

The radioactive content of ALL "intentional" samples sent aloft in the future must be known (measured) before launch. Although peaks from this "baggage" usually do not overlap peaks sought from space-induced activities, their presence at sufficient intensity can interfere with measurement of all peaks of interest which have lower energies than the strong interfering peaks. We documented such a case in last year's report: the presence of relatively high-intensity U-series gamma-peaks in spacecraft parts made of titanium Type 6-4 alloy. In cases where samples are intended for neutron monitoring by production of

slow-neutron capture radionuclides, it is crucial to check for the pre-launch content of these radionuclides, for example: Co-60 in cobalt "intentional" samples. This is especially important when long halflife nuclides are to be measured from short-duration missions, as is the case for Co-60 in cobalt

With improved detection efficiency, increased sample size, and a favorable sample recovery schedule, it is feasible to undertake "frequent flyer" missions on the Space Shuttle with 5- to 10-member sets of "intentional" samples. It is important to build a multi-mission database for this kind of information, initially to test its validity, but mainly to supply important information on characterization of the extra-terrestrial environment into which mankind is just beginning to venture in the context of long-term occupancy.

WHAT'S WITH THE SUN?

Comparisons of the radionuclide content of lunar-surface Apollo Mission machinery with the content of these same radionuclides in natural lunar surface "soil" can, in principle, provide valuable information concerning any changes in the level of solar activity during intervals on the same time scale as the radionuclide halflives. For example, the amount of Ti-44 in Apollo titanium could be compared to the fraction of Ti-44 in lunar surface material that is attributable to the Ti-content of the lunar material. Similar measurements could be made for the Ti-44 content of stainless steel, again comparing it to the Ti-44 in lunar material attributable to its Fe-content. This gives us the 50- to 100-year perspective, during which solar activity has been monitored from earth with some regularity. An even shorter view, a 5-year perspective, could be based on the comparison between the Na-22 content of Apollo aluminum and lunar surface material.

Upon validation of this approach for these time scales, a long-range possibility comes to view: the million-year perspective, afforded by measurement of the 720000-year halflife radionuclide Al-26, by direct counting of its decay. The Al-26 content of lunar surface material has been documented from Apollo Program samples (refs. 3, 4) at approximately 50 d/min-Kg, or about 20 pCi/Kg. One pCi in a kilogram sample is easily measurable with our present systems. The real challenge will be to get it right for the Al-26 in Apollo aluminum, where the 30-year lunar exposure has produced but a tiny fraction of the near-equilibrium Al-26 activity existing in lunar surface material. Simple calculations, based on the efficiency increase provided by New Merlin and the availability of optimum sample size, predict the measurement will be difficult but successful.

Measurement of the long-lived nuclides Na-22, Al-26, Ti-44, and Bi-207 in parts retrieved from dormant earth-orbit satellites can provide additional information regarding the near-earth effects of solar activity. The value of such analyses would be increased if they can be obtained from parts of satellites that have been in orbit for different lengths of time, and/or different orbits.

Another very promising and rapidly developing technique, accelerator-based mass spectrometry (AMS) (ref. 5), is amenable to some of the analytic needs discussed here, especially in regards measurement of the longer halflife nuclides, such as Al-26. In this technique, any of the parent atoms (ionized, accelerated, and magnetically separated) can be counted, instead of only those atoms which decay while the sample is being "watched". Much smaller samples can be analyzed, and in shorter analysis times. AMS becomes ever more suitable as halflives lengthen, and ever more necessary as sample size decreases. The proposed "solar history" measurement of Al-26 may best be accomplished through use of AMS on the lunar surface material and gamma-spectrometry on the Apollo aluminum.

These gamma-spectrometric methods, along with other radiometric techniques, AMS, and conventional mass spectrometry are among the major avenues (ref. 6) toward understanding the extent of solar output variability on the time scale relevant to critical decisions to be made regarding the specter of "global warming" that now confronts our civilization.

SUMMARY

The perspective for this discussion of the LDEF sample analysis effort is forward-looking: evaluation of our experience at obtaining the reported results in the context of improvements that can be implemented during future missions. Examples have been given to emphasize the need for larger samples, as well as more efficient (larger) detectors. Choices for target elements (intentional samples) have been discussed, as well as the schedules for sample retrieval after spacecraft touchdown. Finally, some applications are outlined for use of induced-activity analysis of materials returned to earth after various times in space, as one of the promising avenues toward identifying (any) temporal variations in solar output - - perhaps reaching back as far as a million years.

ACKNOWLEDGMENTS

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We respectfully dedicate all our efforts in the LDEF analysis program to the last crew of the Challenger, lost at launch in early 1986, but long remembered in the annals of man's journey into space.

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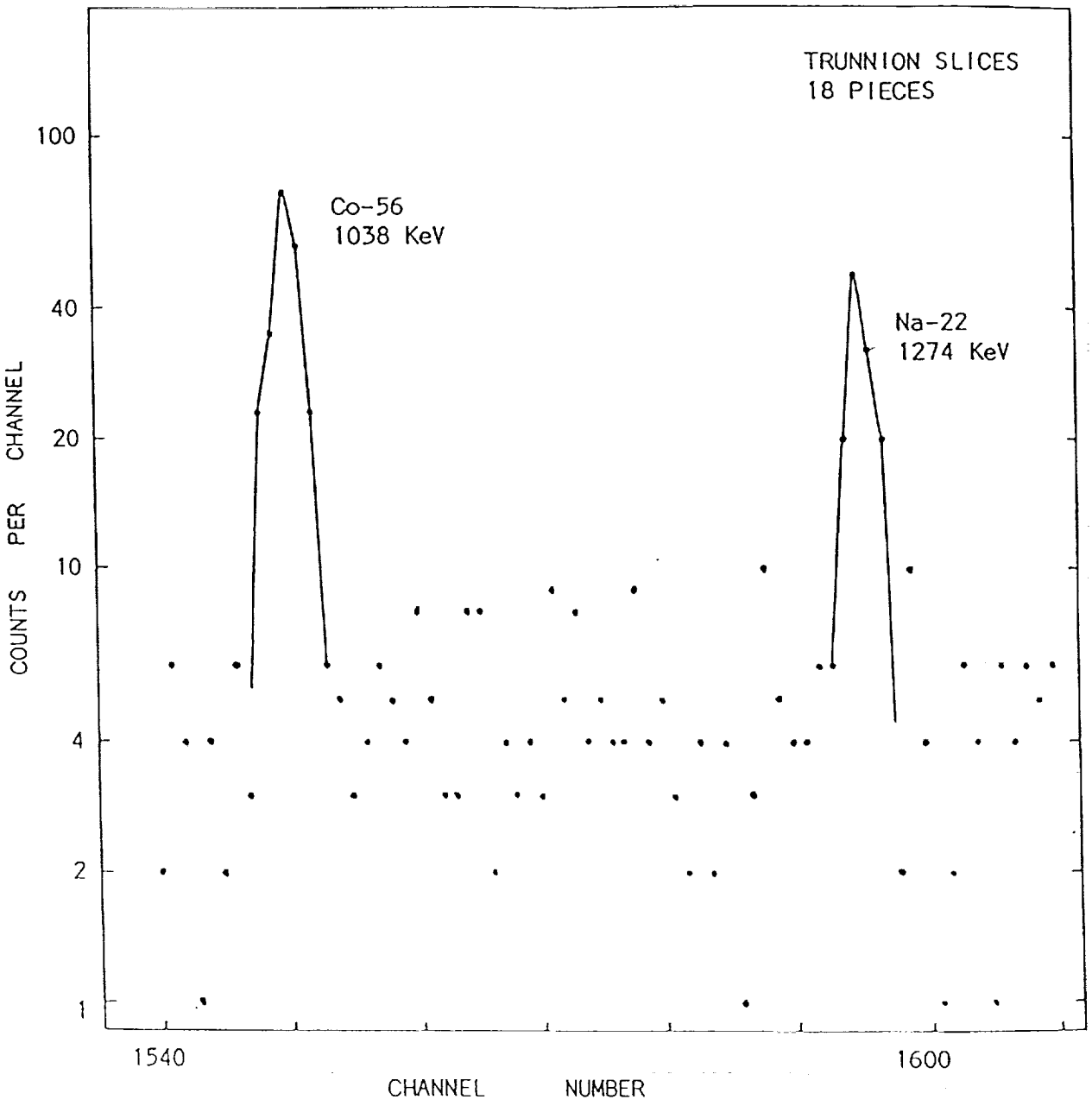

Figure 1. Spectral data from a week-long "Merlin" run on a group of trunnion slices; this interval features the 1274 KeV peak from Na-22.

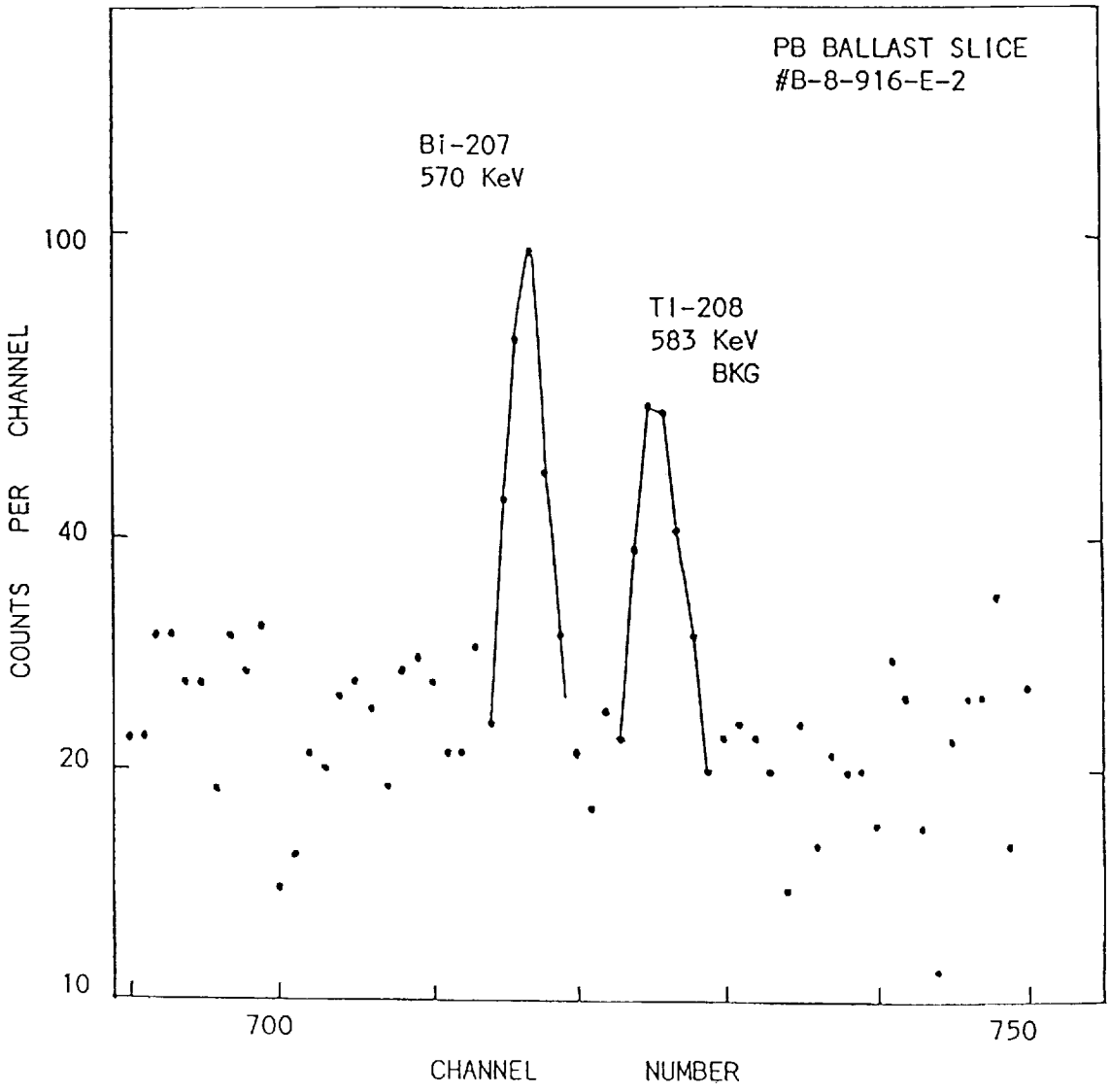

Figure 2. Spectral data from a week-long "Merlin" run on one Pb ballast slice; this interval features the 570 KeV peak from Bi-207, as well as a nearby TI-208 BKG peak, which has an intensity of 0.01 c/min.