COMPUTER AIDED NEUTRON ACTIVATION ANALYSIS

by

HALUK BÖGRÜN

B.S. in Mechanical Engineering
Middle East Technical University
1978

Submitted to the Faculty of the School of Engineering
in Partial Fulfillment of
the Requierements for the Degree of
Master of Science
in

Nuclear Engineering

BOĞAZİÇİ UNIVERSITY

1982
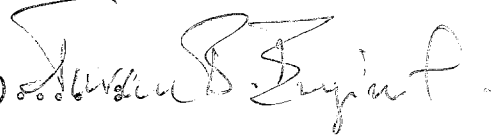
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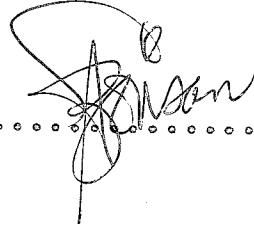
This is to certify that I have read and approved the thesis entitled "A Computer Aided Neutron Activation Analysis", submitted by Halûk Böğrün in partial fulfillment of the requirements for the degree of Master of Science in Nuclear Engineering, School of Engineering, Boğaziçi University.

Date :

1- Dr. Vural ALTIN .... :

2- Doç. Dr. Fahir I. BORAK (Thesis Advisor) .... :

3- Prof. Dr. Turan ENGİNOL (Department Chairman) ....

4- Doç. Dr. İlsen ÖNSAN .... :

ABSTRACT

Neutron Activation Analysis (NAA) has become a widely used and important analytical technique in the determination of the minor constituents of many samples. The composition of these samples may range from macro-quantities (greater than 1%) down to micro-quantities (parts per million). The micro qualitative and quantitative analyses can be performed by NAA. For this purpose the basic concepts and the theory of NAA is introduced. The detection methods and various types of detectors are discussed. The auxiliary electronic equipments and the statistical methods used in the evaluation of the results are also given. A pre-developed computer code, namely CORGAM, is presented in order to unfold the gamma-ray spectra obtained from the activation analysis of mixtures of materials. The code which was previously programmed for the IBM 360/50 computer is updated for use in the BOĞAZİÇİ university computer UNIVAC-1106. The data from a sample problem are used as input to run the program in B.U. computer. The output obtained from this run is observed to fit exactly to the results previously obtained. Finally the program and the input library are recorded onto a magnetic tape, and the necessary information required to run the program is given.

Günümüzde Nötron Aktivasyon Analizi (NAA) yolu ile,çeşitli
malzeme kompozisyonlarında,malzemeyi teşkil eden elementlerin cins ve
miktarlarının tayini oldukça önem kazanmıştır. Bu çalışmada,NAA'nın
dayandığı prensipler,genel teorisi,analiz sırasında kullanılan detek-
tör sistemleri incelenmiş ve neticelerin istatistiki değerlendirilmesi
için kullanılan teknikler tanıtılmıştır.Diğer analitik yöntemlere oran-
la daha hassas sonuç verme üstünlüğüne sahibolan nötron aktivasyon ana-
lizinde sonuçların değerlendirilmesi sırasında karşılaşılan uzun zaman
alan hesaplamalar,bilgisayarların hızlı hesaplama yeteneğinden yararla-
nılarak yapılmaya çalışılmıştır.Bu amaçla,daha önce hazırlanmış olan bir
bilgisayar programından yararlanılmış ve bu program (CORGAM) üzerinde
gerekli değişiklikler yapılarak sadece tasarlandığı üzere IBM 360/50
tipi bilgisayarlarda değil UNIVAC-1106 tipi bilgisayarlarda da kulla-
nılabilmesi sağlanmıştır.Program değiştirilmiş hali ile manyetik bir
banda kaydedilmiş ve gelecekteki uygulamalar için gerekli bilgiler ayrı-
ca sunulmuştur.

ACKNOWLEDGMENT

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1. INTRODUCTION

1.1- GENERAL

The nuclei of atoms are stable only when they contain a certain number of neutrons and protons.The number of neutrons in the nucleus of an atom determines whether that atom is radioactive or stable.(There are exceptions. For a few elements there are no stable nuclei.In some cases,there are other differences that make certain nuclei radioactive.) Thus,while all sodium atoms contain 11 protons, only those sodium atoms that contain 12 neutrons are stable.For other elements there may be more than one number of neutrons that results in stability;for instance there are 10 stable atoms (isotopes) of tin;each containing a different number of neutrons in their nuclei.

The fact that nuclei can absorb additional neutrons,which,in many cases,results in the conversion of a stable nucleus to a radioactive one, makes Neutron Activation Analysis (NAA) possible.Because radioactive nuclei decay in unique ways and yield radiations that are often distinct, and can be measured even in very small amounts,measurements of these radiations can determine the kind and the number of radioactive atoms that are present.

In order to perform NAA, the first condition is that the element of interest gives by some nuclear reaction a radioactive isotope.The probability of the reaction (cross-section),the isotopic abundancy of the target nucleus, and the half-life of the formed isotope should be large enough to allow measurements of th emitted radiation.The type and the energy of this radiation is also of interest,mainly in overcoming nuclear interferences induced by the matrix and the other impurities.

Through its nuclear character,the neutron activation technique allows the analysis of a wide variety of elements in widely differing matrices, making it a powerfull analytical tool not only in trace analysis but also in determining alloy elements and minor constituents.Therefore the field of application of the method is very wide.It has been used to determine traces in ultra pure elements,in biological materials and minerals,in analysis where only small samples are available,in identification of industrial products by trace characterization,in industrial analysis of steel,in geochemistry for the determination of isotopic abundancies,etc.(Al-61,Ch-60,Pi-62)

Although NAA was proposed by von Hevesey and Levi (he-36) followed in 1938 by charged particle activation analysis applied by Seaborg et al.(Se-38) the method was considered as rather a curiosity until mid-forties.Micro constituents analysis by NAA,however became possible only after the development of high flux reactors,accelerators and reliable scintillation spectrometers.Basic principles of NAA are discussed in detail by many authors (So-69,Ba-64,Ev-55,Pr-64,OK-72).In addition some application of digital computers to NAA were presented at a symposium in 1962 (OK-62).

1.2- NEUTRON ACTIVATION ANALYSIS

The irradiation of most atomic nuclei by thermal neutrons causes these nuclei to become radioactive.The subsequent emission of beta or gamma radiationsfrom these nuclei is characteristic of the particular isotope.If the energy of emission of the radiations are known,the isotope can be identified. The magnitude of the radioactivity is directly related to the amount of the isotope present in the specimen.The detection of radioactivity requires sensitive techniques.However neutron activation analysis permits the accurate appraisal of very small amounts of an element.Neutrons are able to pass through a considerable thickness of most substances.It is possible,therefore to analyze materials in solid,liquid or gaseous phases (Wa-63).

Besides the high sensitivity of thermal neutron activation analysis, this technique offers a number of other advantages such as the simplicity of the nuclear reaction,transparency of most materials to thermal neutrons and non-destruction of the sample,etc.In principle this means that in most cases only neutron capture reactions have to be considered and that consequently there is no change in the nature of the irradiated elements.

Unfortunately thermal NAA can not solve a number of important trace analysis problems,as for instance those of light elements,e.g.carbon, nitrogen and oxygen.These problems can sometimes be solved by applying an other method of activating particles:photons or charged particles such as protons,deuterons,helions,etc.If neutron analysis is possible for the whole mass of the sample, this is not true for charged particle analysis as these have a very short range.While all analytical techniques require some chemical treatment before the analysis,the NAA may require the chemical treatment only after irradiation and often after removal of surface contamination.One further advantage of NAA is in many cases the selectivity or even specificity of its nature.It should be remembered that the activation is a reaction of the nucleus,and thus independent of the chemical state of the considered element (So-69).

By applying gamma scintillation spectrometry to activation analysis it becomes possible to analyze simultaneously a number of different elements. A careful statistical treatment can demonstrate that NAA can be as precise and even better than other analytical methods.

The procedure can be summarized as follows: irradiate a sample and a standard under the same conditions;count both under the same conditions; the ratio of these rates will be equal to the ratio of the masses of the element of interest.If one takes activation in a thermal reactor, one should remember among many other parameters that the neutron energy varies from a thermal energy of 0.025 eV up to about 20 MeV.Consequently activation not only occurs with thermal neutrons,but also with epithermal and fast neutrons. Many other complexities may be met during activation,such as unsuspected reactions,production of the isotope of interest by second order reactions or radioactive growth of a daughter isotope,irreproducible geometry,absorption of radiation,instability of the instrumentation,non-linearity in detector response,etc.From this short list of errors it can be concluded that NAA is a complex analytical technique and that experience is required to obtain satisfactory results.

1.3- BASIC PRINCIPLES OF GAMMA-RAY SPECTROMETRY

The basic principle of NAA is the determination of the activity of the product nuclei Y from the activation of the parent nuclei X by means of neutrons. The nuclear reaction of this type can be represented in short notation, as follows

$$X \ (n,k) \ Y \tag{1.1}$$

where n refers to neutron and k to the emitted particles or radiation during the reaction. If the activation process of nuclei X, is assumed to be carried out in constant neutron flux, and if the initial number of atoms of the parent nuclei is also assumed to be constant, then the well known differential equation governing the rate of formation of Y will have the following solution, as given in detail in section 3.2.

$$A_y \equiv N_y \lambda_y = \sigma \phi_o N_x (1-e^{-\lambda_y t}) \ , \tag{1.2}$$

where, A_y is the activity of Y, atoms/sec.,

N_y is the number of atoms of Y,

N_x is the number of atoms of X,

λ_y is the decay constant for product Y, sec.$^{-1}$

ϕ_o is the neutron flux, neutrons/cm^2 sec,

σ is the activation cross-section for production of Y from X, cm^2,

t is the time of irradiation, sec.

When a sample is removed from the neutron flux, the activity begins to decrease exponentially. Then the equation 1.2 becomes,

$$A_y \equiv N_y \lambda_y = \sigma \phi_o N_x (1-e^{-\lambda_y t}) \ e^{-\lambda_y t'} \tag{1.3}$$

where, t' is the corrected decay time to account for decay of the sample during a finite counting time, and is given by;

$$t' = t_r - \frac{t_{1/2}}{0.693} \left[\frac{t_{1/2}(1-\exp(-0.693 \ t_s/t_{1/2}))}{0.693 \ t_s} \right] \tag{1.4}$$

where, t_r is the time from removal from neutron flux to the beginning of the count, t_s is the counting time, $t_{1/2}$ is the half-life of the radioactive product.

The activated atoms will decay to lower energy levels, in order to reach more stable states. If during this decay process, the emitted excess energy is in the form of gamma-rays, both qualitative and quantitative analysis are possible.

The interaction principle of gamma-rays with matter can be used in NAA to identify the gamma emitting isotope and its quantity in the decaying material. In this work main reference is made to scintillating crystals as interacting matter with gamma-rays.

A scintillation detector converts the incoming gamma-rays into scintillations, and into electrical signals through a photomultiplier (PM) tube. These elctrical signals are then amplified, measured and registered. The measurements are performed by the use of multi-channel analyzers (MCA). A MCA is an electronical equipment which stores the electrical signals in different locations (channels) according to their amplitudes. Since the amplitude of the signal is proportional to the incident gamma-ray energy a pulse height versus energy distribution can be obtained. Figure 1.1 is a plot of the expected theoretical response of a monoenrgetic gamma emitter of energy E_O and the actual spectrometer response, i.e., gamma-ray spectrum (He-64).
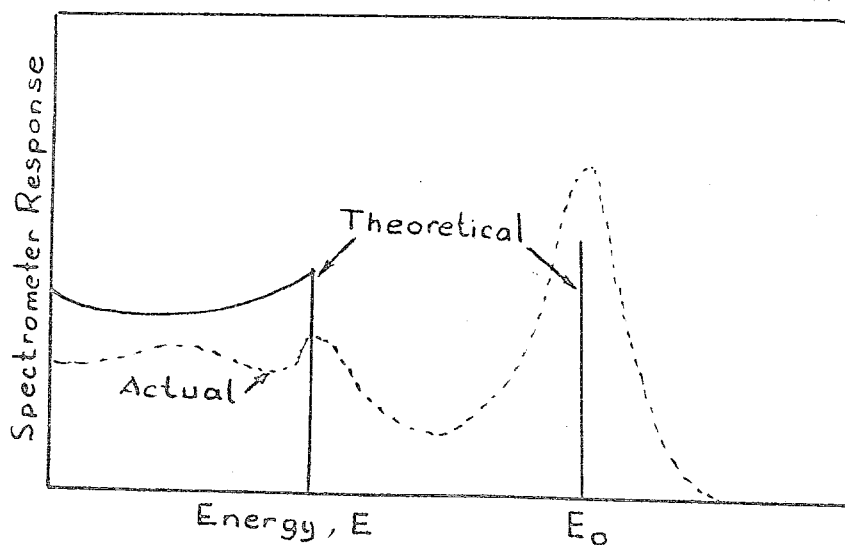
Figure 1.1- Comparison of a theoretical and actual response of a scintillation spectrometer to a monoenergetic gamma emitter of energy E_O (He-64).

1.4- OUTLINE OF THE THESIS

The NAA technique is defined,its use and a brief history is given in section 1. The theory of NAA is briefly stated in the subsection 1.2. Before going into a more detailed study of the general principles of NAA, a short summary of the principles behind NAA are stated and the gamma-ray spectrometry is introduced in the same section. Section 2. is a more detailed discussion of the general principles of NAA.In this section,the interaction of neutrons with matter,formation of radioactive nuclei,their decay schemes are studied.The following subsection defines the types of interaction of gamma radiation with matter.The formation of gamma spectrum is also introduced in more detail in this subsection.The detectors used in common NAA work, their principle of operation,the scintillation process and scintillation detectors are studied in subsection 2.3.Information on the electronic equipment used in NAA and the statistics of radiation can be found in subsections 2.4 and 2.5 respectively.The use of computers in NAA being an important event,some predeveloped computer codes are named in the last subsection of the second section.Among the computer codes which were available in NEA Computer Library (NEA-CPL),CORGAM is analyzed in detail.It is in section 3 that CORGAM is introduced and the theory used in in this computer program is given in some detail in subsection 3.2. One can find the experimental procedures considered in this code in subsection 3.3.In this computer program,there exist some special techniques.These techniques are given in the appendices A,B,C,D and E. Finally a listing of the program,its flow diagram,the input data and the input options,the updating programs and a sample problem run are given in the appendices F,G, H,J,K,L and M.

2. GENERAL PRINCIPLES

2.1- FORMATION OF RADIOACTIVE NUCLEI THROUGH THE INTERACTION OF NEUTRONS WITH MATTER

If a moving particle collides with another one, kinetic energy is exchanged between them in agreement with the laws of conservation of energy and momentum. If the potential energy of the system remains unchanged, kinetic energy being conserved during the collision, the phenomenon is called elastic scattering. The scattering is inelastic if one of the particles is left in an excited state after collision. The symbols (n,n) and (n,n') are often used to denote these processes in neutron elastic and inelastic scattering. Neutrons may disappear in an interaction as the result of absorption reactions, the most important of which, is the (n,γ) reaction. This process is also known as radiative capture, since one of the products of the reaction is instantaneous gamma radiation. Neutrons also disappear in charged-particle reactions such as (n,p) or (n,α) reactions. Sometimes, two or more neutrons are emitted when a nucleus is struck by a high energy neutron. The process here are of the (n,2n) or (n,3n) type. A closely related process is the (n,pn) reaction, which also occurs with highly energetic incident neutrons. Finally, when a neutron collides with certain heavy nuclei, the nucleus splits into two large fragments with the release of considerable energy. This is the fission process. Detailed discussion of these interactions are given in many text books (Ev-55, La-72, Pi-64, Fr-67).

In neutron activation analysis the most important reaction is of the (n,γ) type. This type of reaction is the most common of all reactions, since thermal neutrons induce this reaction in nearly all nuclei. It also occurs with a very high probability for a number of nuclei at particular energies in the epithermal range. This latter phenomenon is known as resonance capture. The gamma-rays which are emitted in the (n,γ) reaction usually have energies of several MeV.

The emission of this gamma radiation is due to the release of excess energy of the excited nucleus. The energy of this gamma-ray is equal to the difference in the energy levels of the excited and stable states of the nucleus. In some cases two or more gamma-rays of discrete energies are emitted in cascade. These gamma-rays are usually emitted within 10^{-13} sec. after the beta-particle, electron capture or alpha-particle decay occurs. Sometimes, this excited state has a characteristic half-life of its own.

Whenever this half-life is of the order of 10^{-7} to 10^{-6} sec. or longer, the excited state is called an isomer of the product atom. And the subsequent decay of this isomer by the emission of a gamma-ray is called an isomeric trasition (Ga-67). The usual case is illustrated by ^{60}Co (Figure: 2.1).
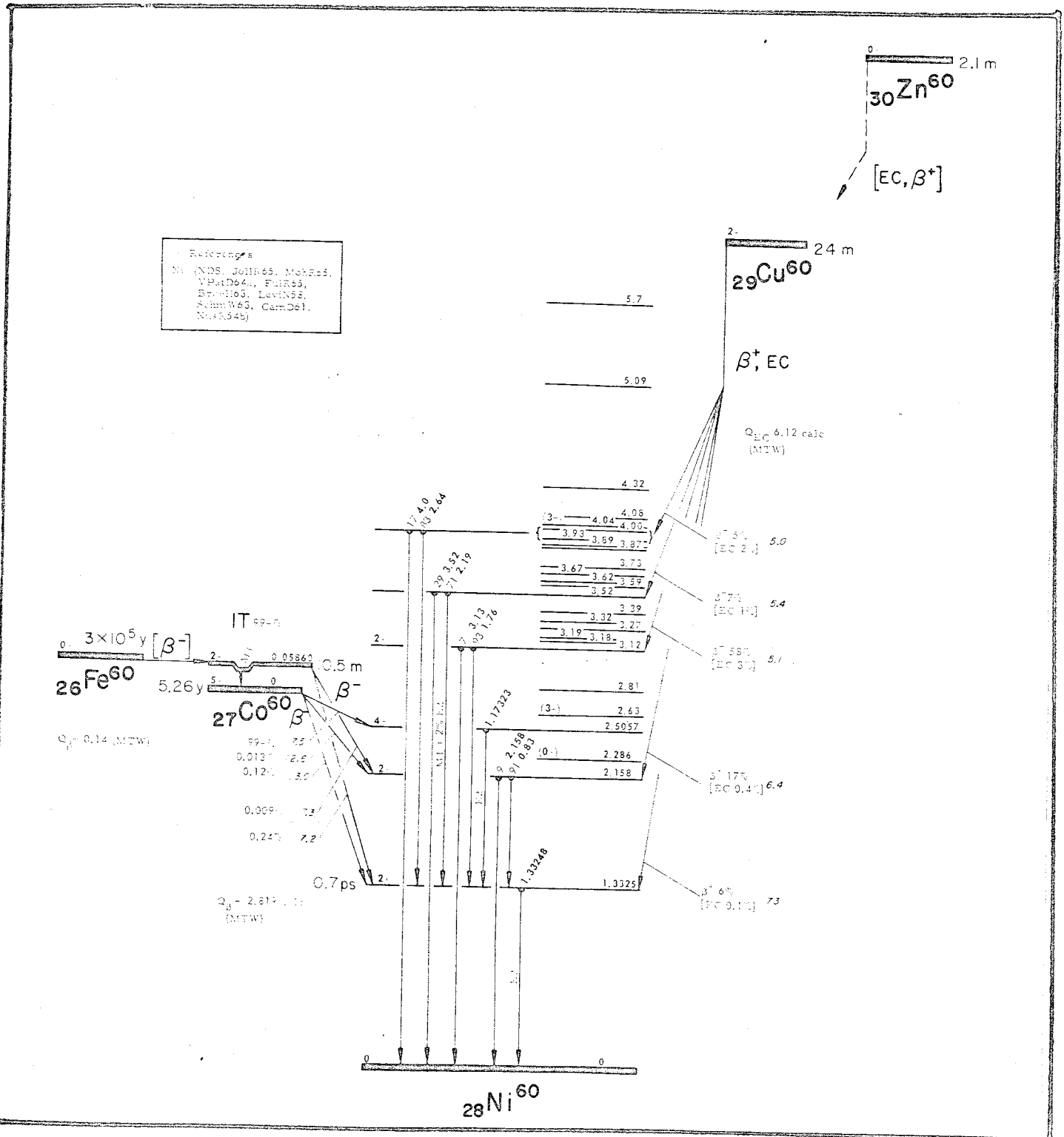
Figure: 2.1- Decay scheme of ^{60}Co (Le-68).

The ^{60}Ni nucleus formed by the β^- decay is rapidly converted from ^{60}Co with emission of 2.50 MeV energy gamma-ray.This conversion takes place by the emission of a photon of 1.17 MeV energy and immediately there-after a photon with 1.33 MeV.A meta-stable state is found e.g. ^{60m}Co (half-life: 10 minutes) which is converted to ^{60}Co by emission of a gamma-ray,which decays as shown in figure 2.1.

In some cases alternative ways for the conversion exist,resulting in a more coplicated decay scheme.In figure 2.2 the decay scheme of ^{137}Ce is illustrated.

Figure: 2.2- Decay scheme of ^{137}Ce (Le-68).

The detection of these gamma radiations by suitable detectors, and the analysis of the spectrum formed by these radiations, may be used to identify the radiating nuclide, its amount, etc. The spectrum formed by these gamma-rays, due to the reasons discussed in the following subsections is unique. That is a given radionuclide has its own spectrum. Once the gamma spectrum is obtained from an unknwn nuclide, qualitative and quantitative analysis is possible by using special techniques. These techniques are studied in detail in many text books (So-69, He-64, Cu-68). A brief description of these methods can be found in the following subsections, and a computer application of a specially developed method, namely the correlation algorithm is presented in section 3 (Ec-68).

2.2- INTERACTIONS OF GAMMA-RAYS WITH MATTER AND GAMMA-RAY SPECTRUM

Gamma-rays, like other electomagnetic radiation, have the properties of both waves and of discrete particles, or quanta. At the relatively high energies of isotopic gamma radiation, the quantum characteristics are the most important. Thus, for the purposes of considering their interaction with matter, gamma photons may be regarded as particles having a given energy. There are four kinds of interaction of photons with matter. Fano (Fa-53) in his article states that these are:

1- Basic interaction with atomic electrons
2- Basic interaction with nuclear particles (nucleons)
3- Interaction with electric field surrounding charged particles (nuclei and electrons)
4- Interaction with meson field surrounding nucleons.

And there are three effects that the interaction may have upon a photon,

A- Outright absorption
B- Elastic (coherent) scattering
C- Inelastic (incoherent) scattering.

Different types of processes may arise from each kind of interaction (1,2,3,4) leading to each of the end results (A,B,C). Thus there are twelve types of processes in all. Many of these processes are quite infrequent, some have not yet been observed. The following three processes are the most important ones. These are;

a) Photoelectric effects, which is the basic interaction with atomic electrons leading to an outright absorption,

b) Compton scattering, which is the basic interaction with atomic electrons leading to inelastic (incoherent) scattering,

c) Pair production, which is the interaction with electric field surrounding charged particles (nuclei and electrons) leading to an outright absorption.

PHOTOELECTRIC EFFECT is most important for photons of low energy. In this process, an incident gamma photon impinges on a bound odbital electron and transfers all of its energy to the electron, ejecting it from the atom. If E_b is the binding energy of the elctron and the recoil energy of the atom is neglected, then $E = h\nu - E_b$, where $h\nu$ is the energy of the electromagnetic quantum and E is the kinetic energy imparted to the electron. The quatum of radiation is possible only because the remainder of the atom can receive some momentum. The photoelectric effect is frequently used to

determine gamma-ray energies.This may be accomplished by measurement of the total ionization due to the photoelectrons in a proportional or scintillator counter.

The photoelectric effect has its highest probability for electrons that are more tightly bound.The incident photon energy must exceed the binding energy of the electron,of course,before this reaction can occur. For incident photon energies above the K-shell binding energy,experiments show that 80 % of the photoelectric effect interactions occur with K-shell electrons.The probability for this interactions,increases rapidly with decreasing photon energies.Figure 2.3 shows now the photoelectric effect probability varies with incident photon energy.
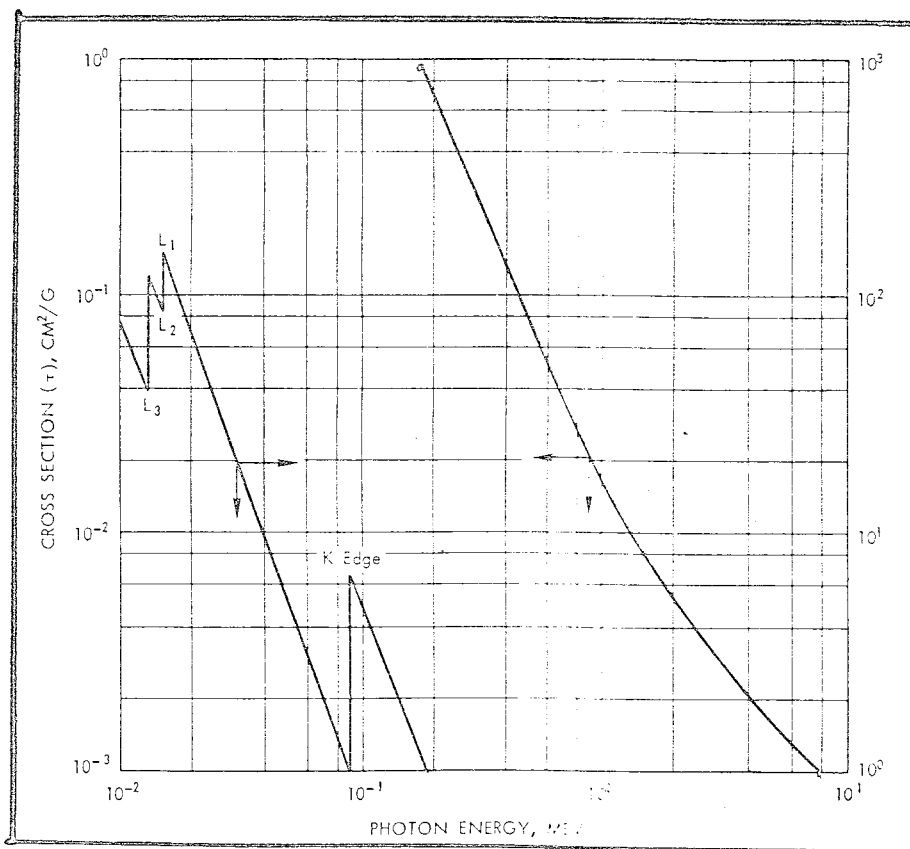
Figure: 2.3- Photoelectric cross-section as a function of photon energy for lead (Ga-67).

The discontinuities occuring at the K and L shell binding energies are called the K and L absorption edges.The probability of photoelectric interaction is approximately proportional to $Z^{4.4}$ of the absorber and to $E^{-3.5}$ of the interacting photon (Ga-67).Thus the photoelectric effect occurs with high Z absorbers and low photon energies.

Instead of giving up its entire energy to a bound electron, a photon may transfer only a part of its energy to an electron, which in this case may be either bound or free; the photon is not only degraded in energy but also deflected from its original path. This process is called the Compton effect or CMPTON SCATTERING named after A.H.Compton who first reported it in 1922 (Ko-61). This effect is shown schematically in figure 2.4.
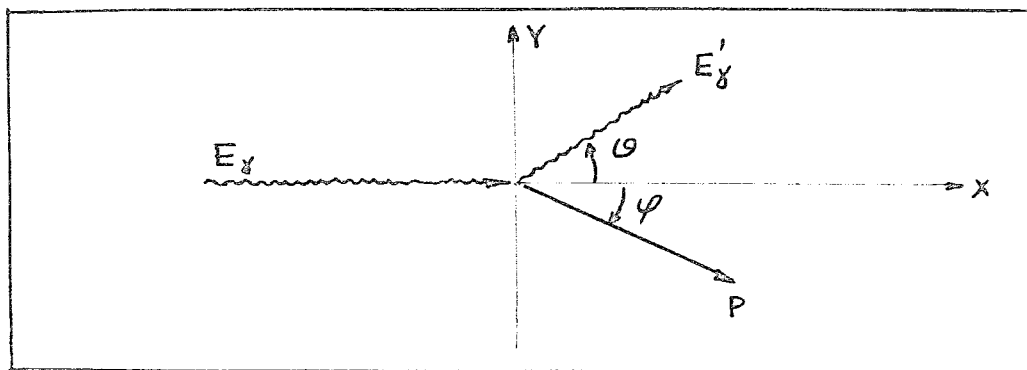
Figure: 2.4- Schematic diagram of Compton scattering of a gamma-ray
by an electron (Fr-67).

Consider the expression which relates the total energy of a particle E to its momentum p.

$$E = \left(E_o^2 + c^2 p^2 \right)^{1/2} \qquad (2.1)$$

The quantity E_o is the total energy of the particle when it is at rest and is given by $m_o c^2$ where m_o is the rest mass of the particle. It must also be recalled that the rest mass of a photon is zero.

If E_γ is the energy of the initial gamma-ray, E'_γ is the energy of the gamma-ray after being scattered by an angle Θ, E_o is the rest energy of the electron (0.511 MeV), p and φ are the momentum of the electron and the scattering angle of the electron respectively. Then the conservation of total energy requires that;

$$E_\gamma + E_o = E'_\gamma + \left(E_o^2 + c^2 p^2 \right)^{1/2} \qquad (2.2)$$

The conservation of momentum along the X direction and Y direction are

$$\frac{E_\gamma}{c} = \frac{E'_\gamma}{c} \cos \Theta + p \cos \varphi \qquad \text{X-direction} \qquad (2.3)$$

$$\frac{E'_\gamma}{c} \sin \Theta = p \sin \varphi \qquad \text{Y-direction} \qquad (2.4)$$

Combining equations 2.3 and 2.4 the following equations are obtained.

$$E_\gamma^2 - 2 E_\gamma E_\gamma' \cos \vartheta + E_\gamma'^2 = c^2 \rho^2$$

(2.5)

$$\frac{1}{E_\gamma'} - \frac{1}{E_\gamma} = \frac{1 - \cos \vartheta}{E_o}$$

(2.6)

Since $E = \frac{hc}{\lambda}$ where c is the velocity of light, equation 2.6 becomes;

$$\lambda' - \lambda = \frac{h}{m_e c} (1 - \cos \vartheta)$$

(2.7)

where m_e is the rest mass of the electron. The quantity $\frac{h}{m_e c} = 2.426 \times 10^{-10}$ cm
is the well known Compton wavelength of the electron. Equation 2.7 shows
that for a given incident energy there is a minimum energy (maximum wavelength)
for the scattered gamma-ray and that this occurs for scattering in the
backward direction ($\cos \vartheta = -1$).

$$\left(E_\gamma' \right)_{min} = \frac{E_o}{2} \frac{1}{1 + E_o/2E_\gamma}$$

(2.8)

For large incident gamma-ray energies ($E_\gamma \gg \frac{1}{2} E_o$) the minimum energy
of the scattered gamma-rays approches $\frac{1}{2} E_o = 250$ KeV. For this reason scintil-
lation spectra of high-energy gamma-rays always show a "back-scattering"
peak at ≤ 250 KeV which is caused by Compton scattering and a valley
between photopeak and Compton continuum whose width corresponds to the
minimum energy (≤ 250 KeV) carried off by gamma-rays Compton scattered
in the crystal (Fr-67).

The Compton effect is important for photons in the energy range of
0.6 to 2.5 MeV. The probability of Compton interaction increases with
increasing Z of the absorber and with decreasing energy of the gamma-ray.

The third mechanism by which electomagnetic radiation can be absorbed
is the PAIR PRODUCTION process. The process is so termed because it results
in the production of a pair of particles of opposite sign, the electron and
the positron. As has been pointed out above, the positron is a particle having
the mass and dimensions of an electron, but a positive rather than a negative
charge. Pai production is possible only for a photon having an energy of at
least 1.02 MeV. When such an energetic photon traverses a powerfull electric
field, such as that surrounding a nucleus, the photon can be annihiliated
with the production of a pair of particles of equal and opposite charge.
In this way, the electrical neutrality of the original photon is conserved.

The energy equivalent of the mass of each particle is 0.51 MeV and the sum of these messes,1.02 MeV, is the minimum photon energy required for production of particles.If the photon has an energy in excess of 1.02 MeV,that excess energy is dissipated as the kinetic energy of the electron and positron created.As in the case of photoelectric effect, the incident photon disappears in this process.The positron so formed is then annihiliuted by collision with orbital electrons,both positron and electron being destroyed in the collision.The energy resulting from the annihiliation process is emitted as electromagnetic or gamma radiation.It can be seen that positron annihiliation is the reverse of pair production,in that the positron is destroyed with the cosequent production of two 0.51 MeV gamma photons. The absorption of a gamma photon by matter through pair production is always associated with the emission of this relatively low energy gamma radiation.

From the figure 2.5 it can be seen that the photoelectric process is the most important process below about 1 MeV.The Compton process is fairly important over the range from 0.1 to 10 MeV,and pair production can take place only above 1.02 MeV.Because a gamma-ray can interact with a detector by these three principal processes,a fairly complex response,Figure 2.6 is obtained from the spectrometer system.The photoelectric process which results in the total deposition of the gamma-ray's energy in the scintillation crystal is characterized by the Gaussian-shaped fll energy-peak. Compton scattering is characterized by the nearly flat continuum below the four small peaks.The backscatter peak corresponds to the photoelectric process for a source gamma-ray whose initial direction of travel was 180° away from the scintillator but was backscattered into the crystal.The energy of the source gamma-ray in excess of the rest mass energy of the electron-positron pair (1.02 MeV) is transferred to the electron-positron pair as kinetic energy.Therfore,a small peak,called the two photon escape peak (or double escape),will occur at a point equal to the source gamma-ray energy minus 1.02 MeV.If one of the 0.51 MeV annihiliation gamma-rays interact in the crystal by the photoelectric process and the other escapes interaction,there will be a small peak,called the one photon escape peak (or single escape),located at a point equal to the source gamma-ray energy minus 0.51 MeV.The third peak,called the annihiliation peak, is a result of photoelectric interaction of 0.51 MeV gamma-rays produced by the pair production process occuring in materials outside the scintillator detector. Because of these interactions,a gamma-ray interacting in a particular scintillation crystal produces a unique gamma-ray spectrum.
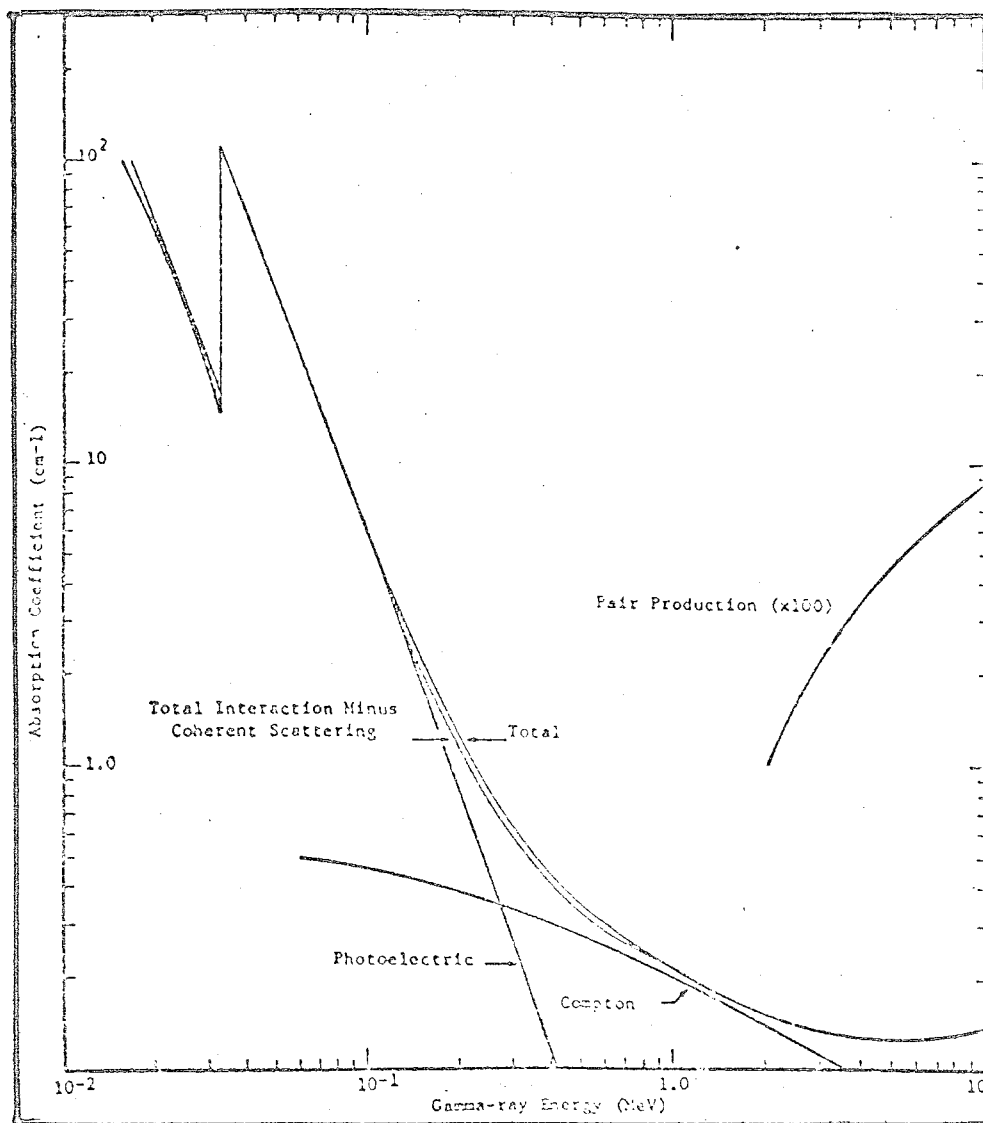
Figure: 2.5- Absorption coefficient for NaI(Tl) as a function of
gamma-ray energy (Ec-68).

The detection of gamma-rays is mostly performed by means of a NaI(Tl)
scintillator or with a Ge(Li) junction.As the output of these detectors is
proportional to the energy of the incident gamma-ray energy,spectrometry is
possible.According to the size and the absorbing properties of the detector
and to the energy of the measured gamma-ray,total or partial absorption can
occur.Figure 2.6 shows the gamma spectra ^{24}Na (E $_1$ 2.76 MeV,E $_2$ 1.38 MeV)
obtained with a 2"X2" NaI(Tl) detector.In this figure (a),(b),(c) represents
the total absorption while (d),(e),(f) denote partial absorption.All
processes giving rise to total absorption contribute to the formation of
the peak at the highest energy side of the spectrum:the so called photo-
peak.The coincidence of two or more gamma-rays in the detector,gives rise
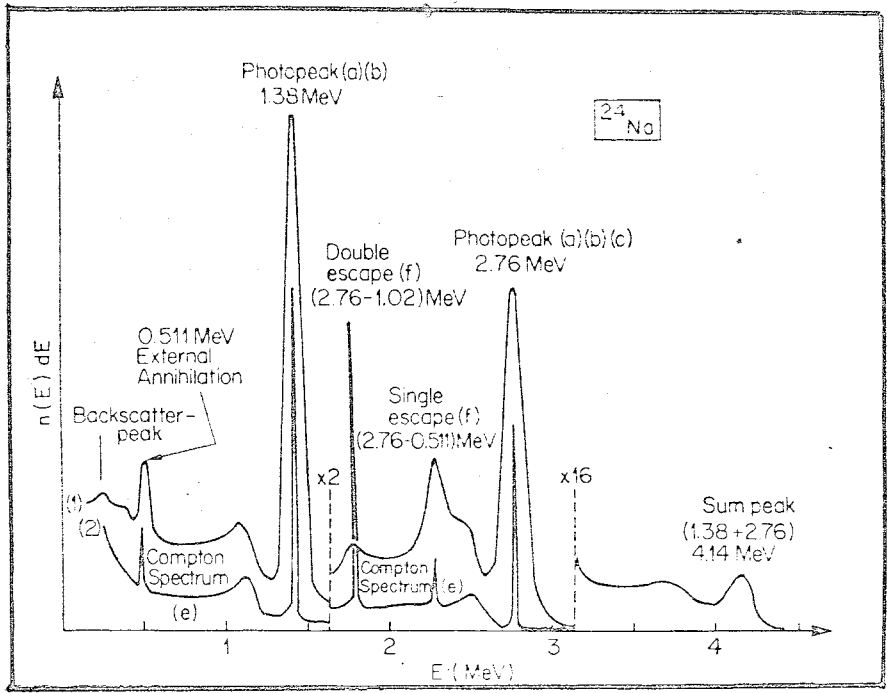
Figure: 2.6- Gamma spectrum of ^{24}Na measured with a NaI(Tl) (1) and with a Ge(Li) (2) detector (So-69).

to a sumpeak.The relative intensity of the sumpeak to the single peak is a function of the source detector geometry.

The energy of the unknown gamma-ray can be determined from the pulse-height of the photopeak maximum.The calibration of the spectrometer can be performed by means of isotopes emitting gamma-rays of known energies. catalogues of gamma-ray spectra measured with NaI(Tl) and Ge(Li) detectors are also available for the identification of gamma spectra (Cr-64,He-64, Le-68).In table 2.1a and 2.1b some calibration sources and respective energies are given.

Quantitative data of the gamma-ray intensity can be obtained from the area or the height of the photopeak.Since radiation is a statistical pheno-menon,the photopeak can be described as a Gaussian error curve.The qualita-tive and quantitative of comlex spectra, can be simplified by computer techniques.The qualitative analysis of the sample by comparison with the standards (reference spectra) can be performed by means of a least squares method,which also allows the calculation of the statistical error.The use of computers can be appreciated in activation analysis not only when dealing with a large number of routine analysis,but also for various tasks,e.g. gamma spectrum analysis,decay curve analysis,statistical treatment of data

optimazing,decay and counting conditions,etc.In section 3 a computer code
"CORGAM" for comlex gamma-ray analysis,is presented in detail.The method
used in this code is given in the subsections of the same section,together
with a complete listing of the program and a sample problem,in the appendice
H,K and L.

Isotope	Energy (keV)	Isotope	Energy (keV)
^{241}Am	59.568 ± 0.017	^{95}Nb	765.83 ± 0.07
^{131}I	80.166 ± 0.009	^{54}Mn	834.84 ± 0.07
^{153}Gd	97.43 ± 0.02	^{88}Y	898.01 ± 0.07
^{153}Gd	103.18 ± 0.02	^{207}Bi	1063.82 ± 0.28
^{177}Lu	112.97	^{60}Co	1173.13 ± 0.04
^{141}Ce	145.44 ± 0.05	^{60}Co	1332.39 ± 0.05
^{139}Ce	165.84 ± 0.03	^{24}Na	1368.40 ± 0.04
		^{56}Co(D.E.)	1576.9 ± 0.32
^{177}Lu	208.36	^{208}Tl(ThC'')(D.E.)	1592.3 ± 0.13
^{203}Hg	279.12 ± 0.05	^{24}Na (D.E.)	1731.6 ± 0.16
^{131}I	364.47 ± 0.005	^{88}Y	1836.1 ± 0.07
		^{56}Co	2035.2 ± 0.50
		^{56}Co(D.E.)	2232.2 ± 0.67
^{198}Au	411.776 ± 0.01	^{24}Na (S.E.)	2242.6 ± 0.14
		^{56}Co	2598.9 ± 0.30
Annihilation	511.006 ± 0.02	^{208}Tl (ThC'')	2614.3 ± 0.09
^{207}Bi	569.65 ± 0.10	^{24}Na	2753.6 ± 0.12
^{137}Cs	661.59 ± 0.07	^{56}Co	3202.4 ± 0.65
		^{56}Co	3254.2 ± 0.65
		^{56}Co	3273.6 ± 0.4
		^{56}Co	3452.5 ± 0.75

S.E. = single escape   D.E. = double escape.

Table: 2.1a- Calibration sources for gamma-ray spectrometry (So-69).

Energies (keV)	Relative energies			
	This work	Ref. 5	Ref. 4	Ref. 2
80.57 ± 0.20	14.48 ± 0.48	14.55 ± 0.45	13.33	14.50 ± 2.9
94.55 ± 0.15	0.3			0.16 ± 0.03
121.60 ± 0.15	0.78 ± 0.18			0.7 ± 0.50
160.70 ± 0.20	0.36 ± 0.15			0.35 ± 0.1
184.50 ± 0.25	100	100 ± 1	100	100
215.60 ± 0.25	3.94 ± 0.09	4.15 ± 0.06	4.44	3.8 ± 0.4
231.20 ± 0.30	0.36 ± 0.03	0.32 ± 0.05		0.3 ± 0.2
260.15 ± 0.30	1.77 ± 0.12	1.42 ± 0.10	1.11	1.8 ± 0.5
280.30 ± 0.30	38.61 ± 0.46	43.6 ± 0.4	33.33	39.5 ± 2.8
300.45 ± 0.40	4.77 ± 0.09	5.45 ± 0.05	4.44	4.8 ± 0.4
365.80 ± 0.30	2.93 ± 0.06	3.72 ± 0.07	2.22	2.9 ± 3
410.95 ± 0.30	15.50 ± 0.19	16.8 ± 0.2	13.33	15.8 ± 1.2
451.55 ± 0.25	3.48 ± 0.07	4.30 ± 0.08	3.32	3.5 ± 0.7
464.90 ± 0.25	2.00 ± 0.07	1.66 ± 0.08	2.22	2 ± 0.4
529.95 ± 0.30	10.16 ± 0.32	13 ± 0.40	13.33	10.3 ± 1
570.50 ± 0.30	6.77 ± 0.14	7.08 ± 0.14	7.77	6.8 ± 0.7
594.90 ± 0.20	1.28 ± 0.18	0.74 ± 0.10		1.2 ± 0.4
610.95 ± 0.15	1.48 ± 0.27	1.59 ± 0.32		1.4 ± 1.0
670.48 ± 0.2	7.01 ± 0.25	7.35 ± 0.29	6.66	7 ± 0.7
691.15 ± 0.15	1.85 ± 0.09	1.62 ± 0.08	1.11	1.9 ± 0.4
711.70 ± 0.20	71.65 ± 0.68	71.5 ± 0.7	64.44	72.5 ± 6
725.50 ± 0.2	0.2			0.19 ± 0.1
736.70 ± 0.20	0.46 ± 0.04	0.50 ± 0.05		0.45 ± 0.15
752.50 ± 0.25	16.06 ± 0.40	15.2 ± 0.30	15.55	16.1 ± 1.2
779.20 ± 0.45	3.72 ± 0.07	3.88 ± 0.06	4.44	3.8 ± 0.3
793.10 ± 0.20	0.2			0.17 ± 0.1
810.80 ± 0.40	76.38 ± 0.82	76.4 ± 0.80	66.66	76 ± 8
830.80 ± 0.30	12.07 ± 0.25	12.9 ± 0.30	12.22	12.5 ± 1.
875.90 ± 0.20	1.14 ± 0.07	0.91 ± 0.04	0.88	1.15 ± 0.15
889.20 ± 0.15	0.7 ± 0.15			0.73
896.50 ± 0.10	0.7 ± 0.15			0.73
951.50 ± 0.20	3.5 ± 0.14	3.16 ± 0.12	3.66	3.6 ± 0.6
995.35 ± 0.25	0.68 ± 0.18			0.73 ± 0.24
1118.10 ± 0.20	0.30	0.26 ± 0.02	0.33	
1147.20 ± 0.20	0.38 ± 0.05	0.26 ± 0.02	0.22	0.38 ± 0.06
1241.80 ± 0.30	1.22 ± 0.05	1.06 ± 0.04	1.11	1.25 ± 0.25
1275.00 ± 0.25	0.75 ± 0.20			0.8 ± 0.15
1283.10 ± 0.20	0.38 ± 0.04	0.22 ± 0.02	0.33	0.8 ± 0.15
1401.30 ± 0.15	0.86 ± 0.05	0.72 ± 0.02	0.77	0.93 ± 0.09
1427.50 ± 0.20	0.65 ± 0.03	0.69 ± 0.02	0.66	0.69 ± 0.07

[a] The intensity 184.50 keV is taken as 100 units.

Table: 2.1b- Energies and relative intensities[a] in the decay of 1200 y ^{166}Ho^m. The errors quoted are one standard deviation.

2.3- SCINTILLATION DETECTORS

One of the oldest methods of nuclear-radiation detection makes use of light scintillations.It is well known that Rutherford and his collaborators used this technique for detecting alpha particles in the famous alpha-sct-tering experiments (Pr-64).The principle of these detectors is the classical one,long used in the spinthariscope also (Pi-62).The same principle is applied in the detectors of radioactivity which are called scintillation counters;these consist of two parts,a scintillator in which the luminous effects are produced,and a photomultiplier (PM) to convert the light pulses into high amplitude electrical signals.The chief advantages of scintillation counters are that they provide pulses proportional to the energy of the particles,and they have high efficiency for gamma radiation as well having large sensitive areas.Before discussing the scintillation detection mecha-nism,it is necessary to discuss the scintillation phenomenon itself.Many materials are excited by radiation and subsequently lose part of this excitation energy by the emission of low energy photons of radiation. However very few materials emit radiation of a wavelength that easily inte-racts with photomultiplier phosphor material and yet easily penetrate common glasses.Even fewer are transparent to their own emitted radiation (Ga-67). Luminescence is the general term describing the absorption of energy of any type by a substance and the reemission of some fraction of it as photons of visible or near visible light.Radiation energy is but one type of energy that can excite materials to initiate luminescence.Two types of luminescent emission can occur.By absorption of energy,electrons can be raised to higher excited states and can return to the ground state either directly or via a metastable state.This deexcitation which occurs in a time shorter than 10^{-8} s is called fluorescence (immediate emission).The energy of the emitted light is less than that of the absorbed one to reach the excited state.The electron occupying a metastable state, can be raised to a higher excited state and subsequently return to the ground state by emission of a photon.This process called phosphorescence, occurs after a time interval of about 10^{-8} sec after excitation (delayed emission).Scintillation theory is discussed in more detail by many authors (Bi-53,Cu-53).

The following groups of materials are known to possess desired proper-ties as scintillators:

      1. Crystalline inorganic substances

      2. Crystalline organic substances

3. Solid organic solutions (plastics)
4. Liquid organic solutions
5. Rare gases

Among the desirable properties for good scintillators are high yield of fluorescent light, transparency for this emitted light, rapid light-emission in combination with the lowest possible phosphorescence and finally, a spectral distribution of the light suitable with regard to the sensitivity of existing photomultipliers.The demands in other respects,(density,size, geometrical shape,etc.) depend on the special situation in which the detector is to be used.A survey of the characteristics of the most commonly used phosphors is given in table 2.2.

Materials	Group	Density gm/cm³	Wavelength of maximum emission A°	Relative pulse height %	Alpha beta ratio %	ev/photon	Decay time nsec
Anthracene crystal	Single cryst. organic	1.25	4470	100	9	65	30
Trans-stilbene crystal	Single cryst. organic	1.15	4110	60	9	100	5
Liquid phosphors	Organic solution	0.86	~4000	40-60	9	150	5
Plastic phosphors	Organic solution	1.06	~4000	28-48	9	150	4
$NaI(Tl)$	Single cryst. inorganic	3.67	4130	210	44	30	250
$ZnS(Ag)$	Single cryst. inorganic	4.10	4500	200-300	100		200
$LiI(Eu)$	Single cryst. inorganic	4.06	4700	70	95		1200

Table: 2.2- Properties of some commonly used phosphors (Pr-64,So-69).

The inorganic scintillators are crystals of inorganic salts,primarly the alkali-halides,containing small amounts of impurities as activators for the luminescent process.The yield of fluorescent light is connected with the existence of luminescent centers in the crystal lattice.For these, the transition from the excited state,to the ground level is accompanied by the emission of a photon.Luminescent centers are created by the addition of certain activating substances.Sodium Iodide,activated by the addition of thallium,is the most widely used scintillator for gamma-ray spectrometry.

The important properties,and the theory of various other scintillators are given in many text books (Pr-64,Bi-53,Cu-53,So-69).

Radiation can be measured by the fluorescence phenomenon if a means of measuring the amount of light produced is available.The photomultiplier tube serves this purpose.A PM tube is a phototube in which the currents of photo-electrons from the tubes cathode is multiplied many times through the process of electron multiplication.The principle elements in each of these tubes are the photocathode for releasing the photoelectrons,the dynodes for producing the electron multiplication,and the anode for collec-ting the current pulse.An incident photon interacts with the photocathode material (usually a mixture of Antimony and Cesium) deposited on the inside of the glass cylinder and produces a photo-electron.A positive voltage applied to the first dynode with respect to the photocathode draws this photo-electron to the dynode.The photo-electron is accelerated sufficiently to cause electron multiplication upon its interception by the first dynode. Several electrons are typically emitted in the interaction of the photo-electron with the first dynode.These,in turn,are drawn to the second dynode which is maintained at a positive potential higher than the first one.The electron multiplication continues in this fashion at each dynode until all the electrons so produced are collected at the anode, which is located at the end of the dynode chain.The amount of electron multiplication at each dynode is a strong function of the voltage between dynodes.An approximate relation for the multiplication factor,M,at each stage is,

$$M = KV^7 \qquad\qquad\qquad (2.9)$$

where V is the voltage in volts and K is a constant,and the total multip-lication is given as :

$$A = M^n \qquad\qquad\qquad (2.10)$$

where M is the multiplication at each stage and n is the number of stages. A more detailed discussion on PM tubes is given by Price (Pr-64).Figures 2.7 , 2.8 and 2.9 are the schematic diagrams of three type of dynode arrangement for PM tubes.

Two important properties of PM tubes are the relative constancy of the electron multiplication factor M and of the transit time of the electrons through the multiplier structure.The former property effects the pulse-height resolution of the scintillation detector and the latter the resol-ving time.The resolution of a detector system is a measure of the extent

to which monoenergetic particles produce pulse heights of a single value.
In gamma-ray spectrometry, the spread in the total-energy peak is a measure
of the resolution, which is normally defined as,

$$R \quad \frac{W_n}{E_n} \quad (100) \tag{2.11}$$

where R is the resolution in %, W_n is the full width at half maximum (MeV),
E_n is the gamma-photon energy (MeV).

^{137}Cs generally is used as a comparison standard for resolution of a
crystal. Literature values for typical resolutions range from 5-13 % (Pr-64).
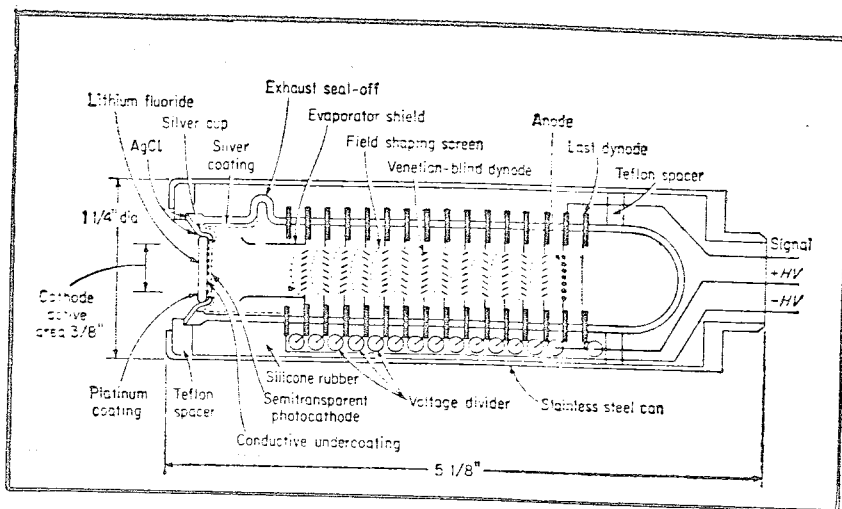
Figure: 2.7- ASCOP photomultiplier tube with Venetian-blind dynode
structure. (Pr-64)
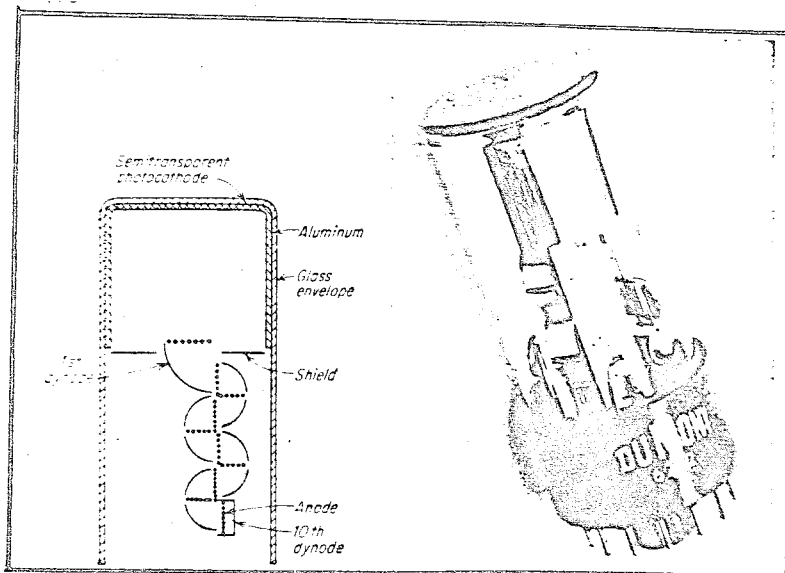
Figure: 2.8- Du Mont 6292 photomultiplier tube; diagram and photograph
Box type dynode structure. (Pr-64)
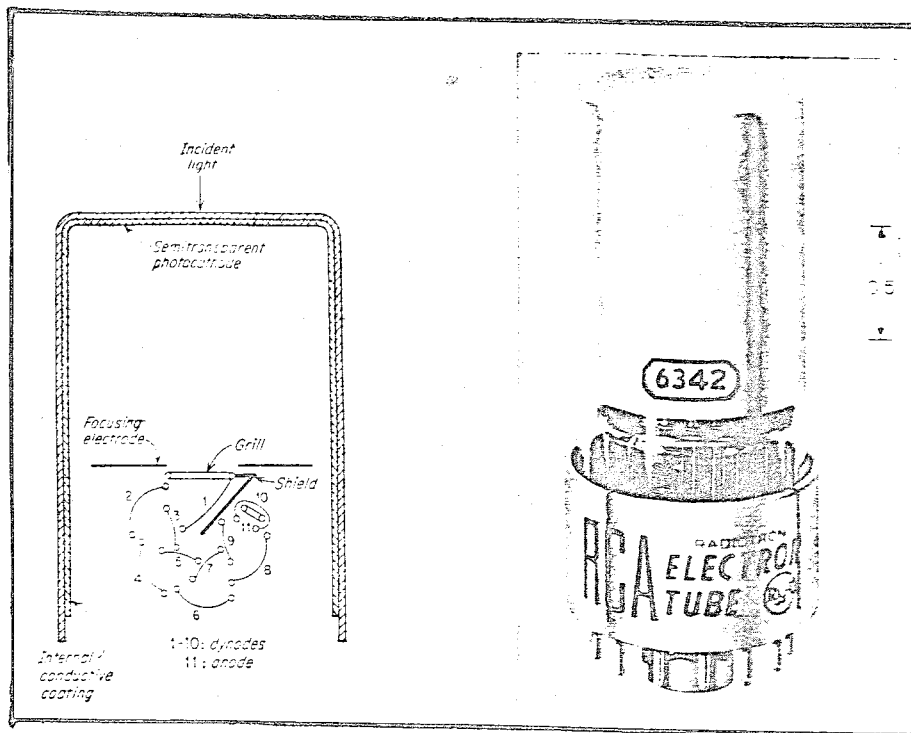
Figure: 2.9- RCA 6342 photomultiplier tube;diagram and photograph circularly focussed dynode structure. (Pr-64)

Figure 2.10 is the pulse-height spectrum obtained with a NaI(Tl) counter for a ^{137}Cs source.
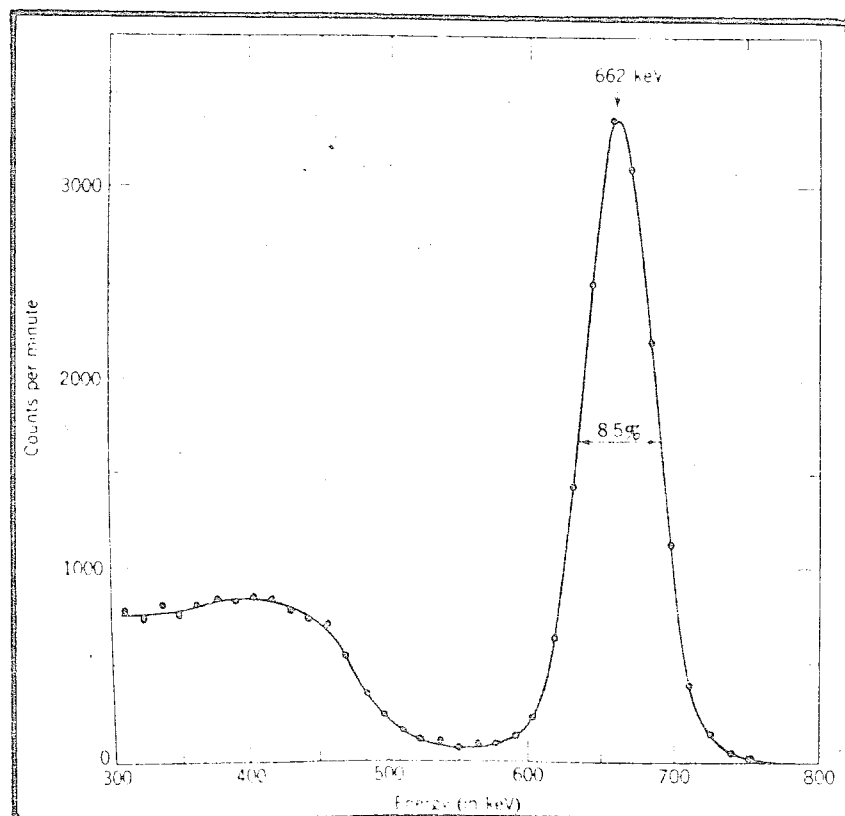
Figure: 2.10- Pulse-height spectrum obtained with a NaI(Tl) scintillation counter for a ^{137}Cs source. (Pi-62)

The resolving time for counting measurements is the minimum time which must exist between succesive events if they are to be counted as two events. Table 2.3 is a compilation of the important properties of various PM tubes.

Type	Maximum outside dimensions, in.		Cathode			Dynode system				Over-all voltage, volts
	Diam.	Length	Area, cm²	Response	Av. sensitivity, μa/lumen	No. of dynodes	Type	Material	Gain	
RCA:										
5819	$2\frac{1}{4}$	$5\frac{13}{16}$	14.2	S-11	50	10	Circ. focused	Cs₃Sb	2.3×10^6	1,250
6342	$2\frac{1}{4}$	$5\frac{13}{16}$	14.2	S-11	60	10	Circ. focused	AgMg	0.55×10^6	1,500
6655	$2\frac{1}{4}$	$5\frac{13}{16}$	14.2	S-11	50	10	Circ. focused	Cs₃Sb	2.3×10^6	1,250
6199	$1\frac{9}{16}$	$4\frac{9}{16}$	7.75	S-11	45	10	Circ. focused	Cs₃Sb	2.8×10^6	1,250
6372	$2\frac{9}{16}$	$7\frac{3}{4}$	80	S-11	33	10	Circ. focused	Cs₃Sb	2.5×10^6	1,200
1P28	$1\frac{9}{16}$	$3\frac{11}{16}$	1.9	S-5	40	9	Circ. focused	Cs₃Sb	5.3×10^6	1,250
6810A	$2\frac{1}{4}$	$5\frac{13}{16}$	14.2	S-11	...	14	Circ. focused	AgMg	12.5×10^6	2,000
8055	$5\frac{1}{2}$	$6\frac{3}{4}$	97	S-11	75	10	Venetian blind	CuBe	1.5×10^6	2,000
Du Mont:										
6291	$1\frac{1}{2}$	$4\frac{1}{4}$	6.4	S-11	60	10	Box	AgMg	2×10^6	2,100
6292	$2\frac{1}{16}$	$5\frac{5}{8}$	13.4	S-11	60	10	Box	AgMg	2×10^6	2,100
6363	.....	$6\frac{1}{8}$	31.4	S-11	60	10	Box	AgMg	2×10^6	1,800
6364	$5\frac{1}{4}$	$7\frac{1}{2}$	88.8	S-11	60	10	Box	AgMg	2×10^6	1,800
6365	$\frac{3}{4}$	$2\frac{3}{4}$	1.26	S-11	50	6	Box	AgMg	3×10^3	1,200
EMI US:										
9536B	2	$4\frac{3}{4}$	14.6	S-11	70	10	Venetian blind	Cs₃Sb	3×10^5	1,700
9545B	$12\frac{1}{2}$	$14\frac{1}{8}$	470	S-11	50	11	Venetian blind	Cs₃Sb	4×10^6	2,000
CBS:										
CL1012	$1\frac{1}{2}$	$4\frac{3}{4}$	8	S-11	60	10	Venetian blind	AgMg	2×10^6	1,750
ASCOP:										
541A	$1\frac{1}{4}$	$4\frac{1}{4}$	5.1	(Depends on window)	70	11	Venetian blind	AgMg	10^6	2,100
543A	2	$7\frac{1}{2}$	14.6	S-11	60	11	Venetian blind	AgMg	10^6	2,100

Table: 2.3- Characteristics of a few commercial photomultipliers.(

Besides scintillation counters a wide variety of detectors are used for radiation detection purposes.A detailed study of these detectors may be found in references (Pr-64,Cr-64,Bi-53,Cu-53,Ko-61,Ga-67,Ev-55).

Gas filled detectors:

Three of the oldest but still very useful nuclear radiation detector types are the ionization chambers,the proportional counter,and the Geiger-Müller (GM) tubes.The difference in the three systems can be seen through the pulse-height versus applied-voltage curves of figure 2.11.The system consists of a gas-filled chamber with a central electrode well insulated from the chamber walls.These detectors use the principle of electrical conductivity of the gas resulting from the ionization produced by the nuclear radiation.

Semiconductor radiation detectors:

In this detector,an electric field is set up across a semiconducting medium of low electrical conductivity.When a charged particle passes through the medium,electron hole pairs are produced in it.The charges are separated by the field and collected at electrodes, producing an electrical signal which can be amplified, recorded and used to give information about the particles detected.

Several other types of detectors are in use and are quite important for specialized detection problems.These detectors are Cloud Chambers, Nuclear Track Plates,Spark Chambers,Cherenkov Counters,Chemical Detectors, Calorimetric Methods, and various types of Neutron Detectors.(Pr-64).

2.4- AUXILIARY ELECTRONIC EQUIPMENT

As it is discussed in the previous subsections the output of a scin-
tillation detector is an electrical signal.In order to analyse this signal
some auxiliary equipment is needed.A complete instrument for the measurement
of nuclear radiation consists of a combination of a detector one or more
electronic units which perform the functions required.The main functions of
these electronic devices are supplying the necessary voltage to the detector
amplifying the detector output signal to a suitable level;registering,pre-
senting and and analysing the amlified signal (Er-64).

Like all others,scintillation detectors also,need a very well stabilized
high voltage supply,which is used to create a potential difference between
the succesive dynodes of the PM tube.Preamlifiers are used where signals
are so small that a normal amplifier is not able to amplify them sufficiently
or where some amplification or impedence matching is required to offset
cable losses.Finally there exists a large variety of electronic equipment
which is used as the analysing apparatus (Pr-64).

One of the important properties of a scintillation detector is its
ability to give an indication of the energy of the incident radiation.Because
of this property,the pulse-height distribution curves from a scintillation
detector can be used to determine the energy spectrum of incident radiation.
The object in pulse-height analysis is to determine the total number of
pulses whose heights fall in selected intervals or channels.If this analysis
is made by sampling one channel at a time, the device is referred to as a
single-channel pulse-height analyzer (SCA).However,in many applications it
is essential to accumulate data without any loss,so multi-channel analyzers
(MCA) are used for this purpose.These instruments all consist of some or all
of the following elements: 1) a section that associates each input signal
with a specific amplitude channel,2) a memory,or data storage device that
contains the information on this number of pulses in each channel until
this information is recorded otherwise,3) a data display device,4) auxiliary
readout devices such as curve plotters,paper-tape or card-punches,magnetic
tape,typewritters,etc.

Below is a block diagram of an electronic arrengement used in pulse-
height spectrometry.An over all discussion of the techniques of MCA's as
well as other methods for pulse-height-to-digital conversion is given by
Chase (Ch-61).

```
┌─────────────────┐ ┌──────┐   ┌──────────────┐   ┌──────┐   ┌───────────┐
│  Scintillation  │ │  PM  │   │  Preamlifier │   │ MCA  │   │ Printer or│
│     Counter     │ │ tube │   │              │   │      │   │  Recorder │
└─────────────────┘ └──────┘   └──────────────┘   └──────┘   └───────────┘
                       │
                 ┌──────────────┐
                 │ High voltage │
                 │    supply    │
                 └──────────────┘
```
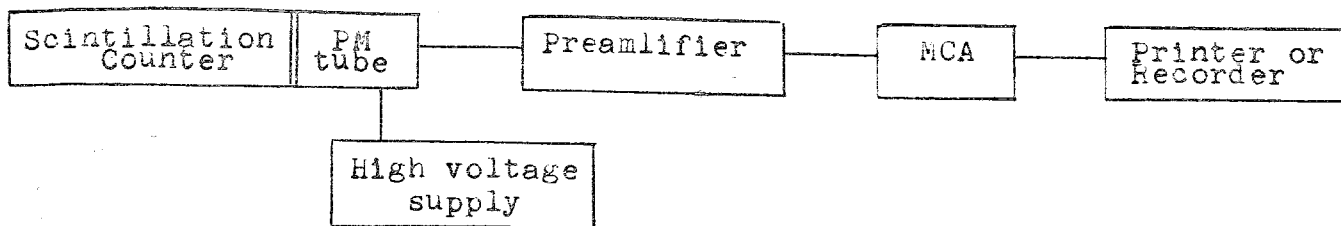
   The most widely used method employs pulse-height-to-time converters.
Figure 2.12 illustrates this process.First the signal pulse "a" is converted
to a flat-topped one "b" by means of a pulse-streching circuit.At the start
of the pulse,a linearly rising signal "c" is switched on,and a series of
equally spaced pulses "d" is started.When "c" reaches "b",the pulse train
"d" is stopped.In this manner the pulse heights are converted into trains
of clock pulses,and different channels now correspond to trains with different
numbers of clock pulses.These trains of pulses can be sorted,stored,displayed
and read out by various techniques that have been developed for digital
computers (Ch-61).
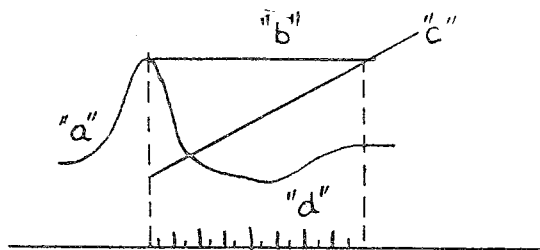
Figure: 2.12- Schematic representation of pulse-height-to-time conversion.

   The MCA's are a logical extension of SCA's.By emloying n differential
discriminators set at succesive window levels and each having its own
counting system,an n-channel analysis is obtained.The principle advantage
of this approach is that its time resolution can be made less than 1 μsec.
However there are two serious disadvantages.First,this arrangement,having
n separate channels consequently n circuits,is costly to construct and
maintain.Second,it is a difficult design to maintain equal window widths.
In general the MCA's are very sophisticated instruments,with good accuracy
and versatility.

2.5- STATISTICAL INTERPRETATION OF THE RESULTS

The measurement of nuclear radiation by the detection systems introduced in previous subsections, involve phenomena which are statistical in nature. By the use of statistical analysis, estimates can be made of the accuracy of the measurements, and procedures can be devised which will minimize errors due to random nature of the process. Obviously, the statistical analysis cannot obviate the need for sound analytical techniques, but unnecessary loss of operator time in the laboratory can be eliminated and the reliability of the results increased by the use of statistical methods.

Two kinds of error can be met in radiation detection; 1) systematic errors, which determine the accuracy of a result, 2) random errors, which determine the reproducibility or precision. By systematic errors the experimental results deviate from the true value, because of a bias. Statistics, on the other hand, deal with random errors. It makes no sense to define an error as the deviation of a measurement from the true value, as the latter is usually unknown. Thus "error" can only be defined after evaluation of the most probable value of the quantity measured. For a number "n" of observations $x_1, x_2, \ldots, x_n$, made under the same conditions and all equally reliable, the arithmetic mean ($\bar{x}$) is the best value for this set of observations.

$$\bar{x} = \sum_{i=1}^{n} x_i / n \tag{2.12}$$

If all observations are not equally reliable a statistical weight W_i can be introduced. The most probable value is then the "weighted mean", sometimes called "general or probable mean" (Gr-74):

$$\bar{x} = \sum_{i=1}^{n} W_i x_i \Big/ \sum_{i=1}^{n} W_i \tag{2.13}$$

The choice on W_i, the weighing parameters, depends upon the experimental conditions and the scatter of data. The reproducibility of an analytical method is usually expressed by the standard deviation $\sigma(x)$ on a single determination. The standard deviation is defined as the square root of the average value of the square of the individual deviations from the most probable value (mean), taken for a large number of observations. Thus,

$$\sigma^2 = \frac{1}{n-1} \sum_{i=1}^{n} (\bar{x} - x_i)^2 \tag{2.14}$$

where n-1 indicates the degrees of freedom of the observation set.

As the arithmetic mean for an infinite number of observations is usually not accessible,it is only possible to calculate the probability that this value is contained within the limits $\bar{x} \pm \Delta x$.The number Δx can be chosen arbitrarily small.It is common practice to express Δx in terms of the standard deviation,e.g. $\pm \Delta x = \pm t\sigma$, where t depends on the probability level and on the number of degrees of freedom.If the latter is large, t is replaced by u.Where "u" is the number of standard deviations for large degrees of freedom.The degree of confidence increases,as the "confidence interval" increases (see table 2.4).

Constant u	Probability P	P'	Error
0.6745	0.500	0.500	"Probable error"
1.000	0.683	0.317	"Standard deviation" (σ) (rms error)
1.177	0.761	0.239	
1.645	0.900	0.100	"nine-tenths error" or "reliable error"
1.960	0.950	0.050	"ninety-five hundredths error"
2.576	0.990	0.010	"ninety-nine hundredths error"
2.807	0.995	0.005	
3.000	0.9973	0.0027	3σ
3.291	0.999	0.001	
4.000	0.99994	0.00006	4σ

Table: 2.4- Probability levels (So-69).

The radioactive decay has a statistical character.If a radionuclide is counted several times in identical experimental conditions,different counting rates (number of counts per unit time) will be observed,even for very long lived species.It can be shown that the probability P(n) of obtaining n disintegrations in a time Δt from N_O original radioactive atoms is given by the Binomial distribution (Fr-67).

$$P(n) = \frac{N_O!}{(N_O-n)! \, n!} \ (1-e^{-\lambda\Delta t})^n (e^{-\lambda\Delta t})^{N_O-n} \tag{2.15}$$

where $(1-e^{-\lambda\Delta t})$ is the probability of an atom disintegrating in a time Δt and $e^{-\lambda\Delta t}$ the probability of surviving through the time Δt.The Binomial distribution may be replaced by the simpler Poisson distribution (Fr-67), the probability P(n) of finding n disintegration is then given by equation 2.16 ,where m is the average to be expected

$$P(n) = \frac{m^n e^{-m}}{n!} \tag{2.16}$$

on condition that $\lambda\Delta t \leqslant 0.01$ and $N_O \geqslant 100$.

For small disintegration rates, the distribution is not symmetrical around $n = m$. For m (or n) > 100 and $m \cong n$ the Poisson distribution can be replaced by the normal or Gaussian distribution:

$$P(n) = \frac{(2\pi)^{-1/2}}{\sigma} \quad \exp\left(-\frac{(m-n)^2}{2\sigma^2}\right) \tag{2.17}$$

where, σ and m designate the standard deviation and the true mean, respectively. Figure 2.13 illustrates the form of the distribution along with its most important properties.
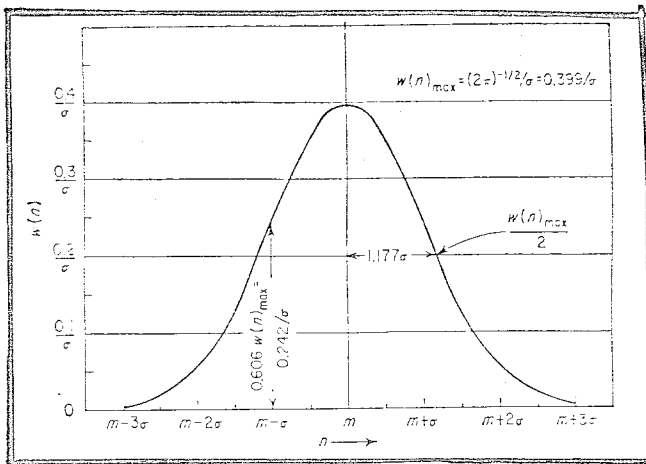
Figure: 2.13- Illustration the normal distribution function (Pr-64).

It will be noticed that this distribution is symmetrical about $n = m$. For the Poisson and Gaussian distributions one may derive $\sigma = \sqrt{m}$, or for large n, $\sigma \cong \sqrt{n}$.

An important concept of statistical interpretation of radioactive disintegration is the confidence intervals, discussed in detail by Curie(Cu-68). If the observed number of counts from a sample + background and from the background alone, for an equal time of measurement Δt, are respectively C_{s+b} and C_b, then the count difference $C_s = C_{s+b} - C_b$ is ameasure of the net activity of the sample. However, owing to the statistical fluctuations, this count difference at the averages of the backgruond $\bar{C}_b$ and the sample $\bar{C}_s$ may obtain various values. At a relatively small value of C_s, the presence of the activity in the sample becomes doubtful. Therefore a so-called "critical value" L_c is introduced, that is often called "decision limit" (Cu-68). For $C_s > L_c$ one assumes that the signal is present, for $C_s < L_c$ the signal will not be detected. Due to this assumption, two kinds of errors may occur:

1-The measured value $C_s > L_c$, one concludes that the activity > 0 when in fact it is equal to zero (type 1 error).

2-The measured value $C_s < L_c$, one concludes that the activity is equal to zero when in fact the activity > 0 (type 2 error).

As appears from figure 2.14, the critical level is mathematically given by:

$$L_c = u_1 \sigma(0) \tag{2.18}$$

The parameter u_1 is a multiple of the standard deviation, determining the probability of making the type 1 error. Usual values for u_1 are 1.645, 1.960, 3.000. Contrary to table 2.4 , this does not correspond to a confidence level of 90,95 and 99.73 % respectively but to a confidence level of 95,97.5 and 99.865 % respectively. Indeed the probability of making the type 1 error is respectively 5,2.5,0.135 % only (one side of the Gauss curve). For that reason, the symbol u has been replaced by u_1.
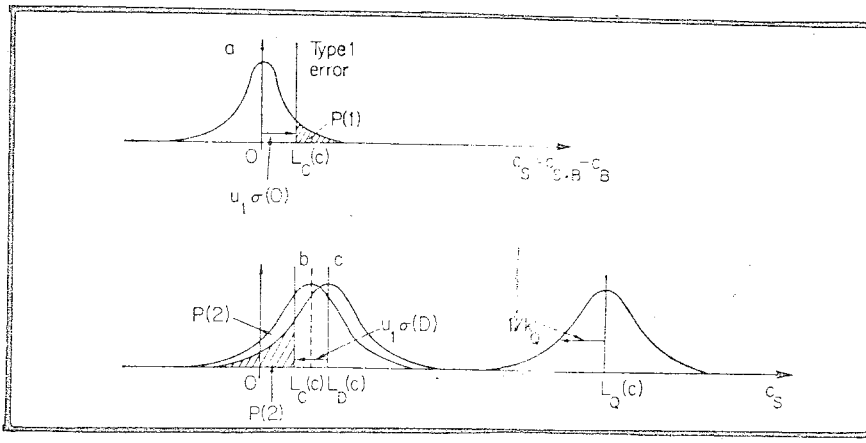
Figure: 2.14- Signal detection. Definition of critical level L_c (So-69).

A number of tests have been devised to answer the question as to whether or not a given set of data fits a certain distribution function. The concept of Poisson's index of dispersion is particularly useful in this regard. To make this test, the quantity χ^2, defined as

$$\chi^2 = \frac{\sum_{i=1}^{n}(\bar{x}-x_i)^2}{\bar{x}} \tag{2.19}$$

is calculated. here n is the number of times that a given counting determination is made, x_i is the value obtained in the ith measurement, and $\bar{x}$ is the

averege value. If the value of χ^2 is sufficiently large so that there is only a small probability of occurence of a value this high, it is an indication of trouble in the experiment. Likewise if χ^2 is small, the corresponding data should be questioned because the spread in it is so small. Thus it is seen that the Poisson index-of-dispersion test can be helpful in determining whether or not the counting equipment is functioning satisfactorily.

Chauvenet's criterion is frequently used for the rejection of outlying data. The criterion states that any one in a series of n readings may be rejected when its deviation from the mean of the series is such that the probability of occurence of all deviations from the mean as large or larger is less than n/2 (So-69, Gr-74).

An overall application of statistical methods briefly mentioned here can be found in the computer code CORGAM, which is introduced in section 3.

2.6- USE OF COMPUTERS IN NEUTRON ACTIVATION ANALYSIS

When experimental data resulting from an activity counting and thus subject to statistical fluctuations,have to be treated,a smoothing routine can be desirable.This is the case when dealing with gamma spectra or decay curves,which have to be analyzed by means of a computer.The simplest smoothing routine is the grafical smoothing,but it can be applied only when data are grafically evaluated.

Mathematical data convolution techniques largely correct for statistico scatter.The simplest convolution sets the convolution integer equal to one, giving rise to a "rectangular" convolution,i.e.,a normal moving average. One also can use a symmetrical triangular convolution,one-sided exponential or symmetrical exponential convolution.But a more exact procedure can be achieved by using a least squares method.In this technique one tries to fit the best curve through the set of points under consideration.In this way it is possible to obtain a set of equations of the nth order with 2n+1 coefficients as unknowns.It is obvious that the calculations needed for one smoothed point are time consuming.

After data smoothing,the analysis of the gamma spectra can be performed in several ways.With the development of high resolution detectors,using a large number of channels per spectrum,the computer becomes practically unavoidable for analysis purposes.

The location of the photo-peak in a gamma spectrum,and the calculation of the corresponding area is of extreme importance in NAA.This can be done by a computer program,and qualitative and quantitative analysis can be made possible in this way.The technique employed in photo-peak positioning is the use of the first derivative of the smoothed spectrum.The exact location of the peak can be found by means of the second derivative.Both, first and second derivative can be calculated according to the least squares method.

Once the photo-peaks have been located,the activity under the peaks can be determined by subtracting the detector background.As the net photo-peak activities are obtained,one could conceive a complete activation analysisi program.By treating the spectra of standards and samples in the same way,and correcting for irradiation time,decay time,and counting time, the results of the analysis can be computed.When the components or constituents of a complex gamma spectrum are qualitatively known,as is often the case in NAA,the only problem is to determine "how much" of each is present

in the sample.From a complex spectrum and from the spectra of composing standards one can compute the best value for the ratios of each component to its respective standard and also the standard deviation (So-69).

A great number of computer programs are available,for the analysis of complex gamma-ray spectra (NEA-CPL).Among them the ones recently prepared are given in the appendix N.

3. CORGAM

3.1- CORGAM-A COMPUTER CODE FOR NEUTRON ACTIVATION ANALYSIS

The importance of computers in NAA was mentioned in previous sections, and a list of computer programs developed for the analysis of gamma-ray spectra is also given in appendix N.

Each of these codes have their own techniques in unfolding complex gamma-ray spectra. All these codes are prepared in order to estimate the intensity coefficients of the general linear hypothesis, which will be discussed in the subsection 3.2. There are many methods for estimating these coefficients. These methods, stripping, least squares, incremental, iterative, vector analysis, and stepwise regression, have been used for estimating these coefficients. All of these procedures may use either least squares or approximate least squares techniques. "Regression analysis" has been used to describe the least squares procedure for fitting a dependent variable, e.g., a complex spectrum, to a set of independent variables, e.g., a set of referance spectra. Because a model is used in which only significant variables are retained in the final solution, a more appropriate description for this work is "Correlation Analysis". (NEA-CPL, Ec-68).

Among the codes available by NEA-CPL in the experimental data processing field, "CORGAM" (A Correlation Algorithm for Gamma-Ray Spectra) is the one which uses correlation analysis in unfolding gamma-ray spectra.

In the present section of the thesis, a detailed description of CORGAM will be given. The listing of the program, flow diagram, input data for sample problem, instruction for users and the output of a sample problem are given in the appendices.

In CORGAM, a correlation algorithm is coded to allow the unfolding of comlex gamma-ray spectra, typically collected in a NAA procedure.

CORGAM,

      a) Compansates for electronic shifts in the data,

      b) Corrects for the background,

      c) Normalizes the data to a fixed neutron flux level,

      d) Allows a choice of weighting factors,

      e) Allows a choice of methods for calculation of standard

         deviations.

The code requires a matrix of reference gamma-ray spectra. These spectra

can be in a raw data form.All of the modifications available to the complex
gamma-ray spectra are also available to the reference gamma-ray spectra.
In addition,a decay correction is available for the reference gamma-ray
spectra.Only the reference gamma-ray spectra that have intensity coefficients
which have significance at a prescribed level of significance are retained
in the final solution.The intermediate ones,i.e.,those solutions that contain
reference gamma-ray spectra which have nonsignificant intesity coefficients
at the prescribed level,are printed out.Therefore,several solutions are
imbedded in the final solution.

A backward elimination least squares method is employed.The elimination
is one in which the student's t value of each intensity is compared to a t
value at a prescribedlevel of significance (Gr-74).The calculation of the
standard deviation for each intensity coefficients accounts for randomness
in both the complex and reference gamma-ray spectra.

Currently the program is restricted to a problem of 400 channels and
15 reference spectra.There would be no difficulty in expanding this to as
many as 4096 channels.However,the number of reference spectra is limited
by the accuracy desired in the inversionprocedure.The inversion program
currently being used would suffer (from the accuracy standpoint) if the
number of reference spectra were greater than 25.

CORGAM is a novel method of unfolding complex gamma-ray spectra because
the variance calculations include contributions from both the complex and
reference spectra.Also,only reference spectra that have intensity coefficients
which are significant at a preselected level are retained in the output.
The intermediate results can be printed,and the level of significance of
each of the intensity coefficients can be observed.

A typical analysis,involving 256 channels and 14 reference spectra
and using reference spectra which were suitably aligned,requires less than
1 minute of execution time on IBM 360/50.

CORGAM was coded for IBM 360/50 using Fortran IV,level G.An intemediate
disk storage is required.The source deck contains 1303 cards.The code is
updated by the author for UNIVAC-1106 using Fortran IV and Cobol.The updated
form of the code is recorded onto a magnetic tape for further use in
BU-NE Department.

The tape contains in the,

1.File: IBM 360/50 version of CORGAM sample data,

2.File: UNIVAC-1106 version of CORGAM,

3.File: Sample problem input data,

4.File: Sample problem output data.

3.2- THEORY OF CORGAM

If a nuclear reaction, such that

$$X (n, \gamma) Y, \tag{3.1}$$

is forced to proceed, the radioactivity of the product nuclei Y, is directly proportional to the number of of the atoms of the parent nuclei X. The equation governing the rate of formation of Y is given by the well known differential equation.

$$\frac{dN}{dt} = \overset{\circ}{N} = \sigma N_o \phi - \lambda N \tag{3.2}$$

where,

N is the time dependent nuclide (Y) concentration,

$\overset{\circ}{N}$ is the derivative with respect to time,

N_o is the time dependent parent nuclide (X) concentration,

σ is the microscopic activation cross-section,

ϕ is the time dependent neutron flux.

The parent nuclide concentration can be given in terms of N and the initial parent nuclide concentration, N_o^O, as

$$N_o = N_o^O - N \tag{3.3}$$

Therefore equation 3.2 can be written as,

$$\frac{dN}{dt} = \overset{\circ}{N} = \sigma \phi N_o^O - (\lambda + \sigma \phi) N \tag{3.4}$$

If the neutron flux is a constant $\phi = \phi_o$ then equation 3.4 has the following solution,

$$N = \frac{\sigma \phi_o N_o^O}{(\lambda + \sigma \phi_o)} \quad (1 - e^{-(\lambda + \sigma \phi_o)t}) \tag{3.5}$$

It can be seen from equation 3.5 that the time dependency of N_o can be ignored if $\sigma \phi_o \ll \lambda$ or $\sigma \phi_o / \lambda \ll 1.0$.

The following table is a compilation of λ, σ and $\sigma \phi_o$ values for many of the elements used in common NAA work. The value for ϕ_o used in this table

of the Nuclides" by D.T.Goldman 1965.

Isotope	$t_{1/2}$ $sec \times 10^{-3}$	λ $sec^{-1} \times 10^4$	$\sigma^a \phi_0$ $sec^{-1} \times 10^{11}$	$\sigma \phi_0 / \lambda$
Na^{24}	54.00	0.128	0.13	1.01×10^{-7}
Mg^{27}	0.57	12.160	0.03	2.47×10^{-10}
Al^{28}	0.14	50.220	0.23	4.55×10^{-10}
S^{37}	0.31	22.650	0.14	6.16×10^{-10}
Cl^{38}	2.24	3.097	0.43	1.39×10^{-8}
K^{42}	44.64	0.155	1.10	7.09×10^{-7}
Ca^{49}	0.53	13.120	1.10	8.38×10^{-9}
Ti^{51}	0.35	19.910	0.14	7.03×10^{-10}
V^{52}	0.23	30.640	4.90	1.60×10^{-8}
Mn^{56}	9.29	0.746	13.30	1.76×10^{-6}
Cu^{64}	46.44	0.144	4.50	3.12×10^{-7}
Br^{80}	1.08	6.416	11.40	1.78×10^{-7}
Br^{82}	127.08	0.055	3.20	5.87×10^{-6}
I^{128}	1.50	4.620	6.40	1.39×10^{-7}

Table: 3.1- Compilation of nuclear properties of several isotopes (Ec-68).

The values for $\sigma \phi_0 / \lambda$ given in table 3.1 been much less than unity, the time dependency of the equation 3.5 can be ignored. With these assumptions equation 3.2 can be solved to obtain A, an expression for activity,

$$A \equiv \lambda N = \sigma N_0 \phi_0 (1-e^{-\lambda t}) e^{-\lambda t'} \tag{3.6}$$

where t is the time of neutron flux exposure, t' is the time after removal from the neutron flux, ϕ_O is the neutron flux, a constant.

When the activity is predominantly gamma radiation, both a qualitative and quantitative analysis can be performed through the use of a gamma-ray spectrometer system and the proper data analysis procedure.

The gamma-ray spectrum of a complex sample containing several isotopes (m in number) may be represented by:

$$y_i = \sum_{j=1}^{m} B_{ij} \quad , \quad i = 1, 2, 3 \ldots n \tag{3.7}$$

where, y_i is the counts registered in channel i of a MCA,

B_{ij} is the counts registered in channel i from j^{th} costituent isotope

Reference gamma-ray spectra are collected for each of the m constituent isotopes using known quantities of radioisotopes. The reference gamma-ray spectra of each of the m constituent isotopes are related to the complex gamma-ray spectrum by,

$$y_i = \sum_{j=1}^{m} x_{ij} B_j + e_i \quad , \quad i = 1, 2, 3, \ldots \ldots m \tag{3.8}$$

where, B_j is the intensity coefficient for isotope j, i.e., a coefficient proportional to the quantity of isotope j in the complex sample,

x_{ij} is the counts registered in channel i from the jth isotope of known quantity,

e_i is the deviation at point i of the estimated value of y_i, $\sum_{j=1}^{m} x_{ij} B_j$, from the observed value, y_i,

Since negative quantities of radioactivity are physically impossible, the following restriction is necessary:

$$B_j \geqslant 0 \quad , \quad j = 1, 2, 3, \ldots \ldots m \tag{3.9}$$

Equation 3.8 and inequality 3.9 form a constrained general linear hypotesis. Therefore, the problem is to estimate the intensity coefficients. The minimization of the sum of the squarred error, i.e., least squares, generally yield estimators for the intensity coefficients with desirable statistical properties, e.g., least squares estimators are unbiased if the data are free of systematic errors (Ec-68).

The linear hypothesis, in matrix form, is

$$\underline{Y} = \underline{XB} + \underline{e} \tag{3.10}$$

where,

Y: (nxl) vector of dependent variable values,

X: (nxm) matrix of independent variable values,

B: (mxl) vector of solution values,

e: (nxl) vector of errors (deviation values),

n: number of data points (channels),

m: number of reference isotopes.

The sum of the squared errors is given by:

$$e'e = (Y-XB)'(Y-XB) ,$$ (3.11)

which reduces to,

$$e'e = Y'Y-2B'X'Y'+ B'X'XB$$ (3.12)

The estimator, b for B results from minimizing $e'e$. If the elements of B are linearly independent, $e'e$ is differentiated with respect to each element of B, term by term, the result is equated to zero, and arranged in matrix form after B is replaced by its estimator, b. This results in:

$$(X'X) b = X'Y$$ (3.13)

The estimate, b, is obtained by solving equation 3.13 for b:

$$b = (X'X)^{-1}(X'Y)$$ (3.14)

Irrespective of the error probability distribution function, the estimates, b, for the true parameters, B, calculated from equation 3.14 minimize the sum of the squared error. Rewriting equations 3.13 and 3.14 and including the error variance-covariance matrix, the following equations are obtained (Gr-74)

$$(X'V^{-1}X) b = (XV^{-1}Y)$$ (3.15)

and $$b = (X'V^{-1}X)^{-1}(X'V^{-1}Y)$$ (3.16)

where V^{-1} is the inverse of the error variance-covariance matrix and is often denoted as a weighting matrix, W.

$$W \equiv V^{-1}$$ (3.17)

If the errors are assumed to be statistically independent, the covariance terms for e will be zero and estimate for the variance of e_i, $\sigma^2(e_i)$, can be obtained from,

$$\sigma^2(e_i) = \sigma^2(y_i) + \sum_{j=1}^{m} \left[B_j^2 \, \sigma^2(x_{ij}) + x_{ij}^2 \, \sigma^2(B_j) \right] \qquad (3.18)$$

where $\sigma^2(x_{ij})$: the variance of the counts in channel i from isotope j
$\sigma^2(B_j)$: variance of the estimator for the jth isotope.

An iterative approach is used to solve for b, as follows:

1. Estimate $\sigma_1^2(e_i)$, given in equation 3.18 using only $\sigma^2(y_i)$,
2. Calculate the first estimate, b_1, of b given in equation 3.16 using the estimated $\sigma_1^2(e_i)$ from step 1.,
3. Estimate $\sigma_2^2(e_i)$ by using b_1 for B and $\sigma^2(b_1)$ for $\sigma^2(b)$ in equation 3.18,
4. Calculate b_2 using the estimated $\sigma_2^2(e_i)$
5. Continue this procedure until a termination criterion is met.

This iterative procedure can be mathematically stated as,

$$b_n = (X' W_n X)^{-1} (X' W_n Y) , \qquad (3.19)$$

$$W_{in} = \left[\sigma_n^2(e_i) \right]^{-1} = \left\{ \sigma^2(y_i) + \sum_{j=1}^{m} \left[b_{j_{n-1}}^2 \, \sigma^2(x_{ij}) + x_{ij}^2 \, \sigma_{n-1}^2(b_i) \right] \right\} \quad (3.20)$$

$$b_{j_o} = \sigma_o^2(b_j) = 0 \qquad (3.21)$$

The termination criterion used is:

$$\chi^2/DF \leq 1 + U_p \sqrt{(2/DF)} \qquad (3.22)$$

where,
χ^2: Chi squared, i.e., $\displaystyle\sum_{i=1}^{n} \frac{\left[y_i - \sum_{j=1}^{m} x_{ij} b_j \right]^2}{\sigma^2(e_i)}$

U_p: Confidence interval factor,
DF: Degrees of freedom, i.e., n-m-1,
/DF: is called the quality of fit number.

U_p factor corresponds to a desired level of significance. Since the numerator of χ^2 is the minimization criterion used in this method, it is not reasonable to assume that the iteration procedure will increase χ^2/DF. Therefore, only a one-sided region is included in equation 3.22 (Ec-68). The mathematical model of this approach can be found in some detail in

The least squares is a logical method to determine the intensity
coefficients for NAA problem (Ak-77). However, one of the difficulties
in applying least squares technique to the resolution of gamma spectra
is that the calculated intensity coefficients can be negative or it may be
difficult to determine the reference spectra that comprise the complex
spectrum. For example, the least squares technique may yield positive inten-
sity coefficients for all the reference spectra, but some may not be signi-
ficant. To overcome those difficulties, the t value for the null hypothesis
is calculated for each intensity coefficient (Gr-74). The t values then are
used in the correlation algorithm to eliminate reference spectra for which
the calculated intensity coefficients are negative or not significant.
An outline of the correlation algorithm used in the code is given in
figure 3.1. Some of the statistical techniques used in CORGAM, namely,
properties of estimators, least squares technique, curve fitting method,
interpolation and determinant evaluation methods are given in the appendices
And a more detailed logic diagram is also given in the appendix J. If needed
a complete description of the methods used in CORGAM can be found in its
manual.

This code, CORGAM has been used to analyze many gamma-ray spectra
from several cereal and feed grain samples (Ec-68). Each sample was irra-
diated in the rotary specimen rack of a KSU TRIGA Mark II nuclear reactor
at 100 kW power for 15 minutes. A zmall (0.02 gm) copper powder sample was
irradiated with each grain sample. The area of the 0.511 MeV photopeak
from ^{64}Cu was used for neutron fluence normalization. Each sample was
transfered to a nonirradiated container and was counted at 10 cm from
3" x 3" NaI(Tl) scintillation crystal, which was interfaced to a TMC-4096
multiparameter system. The reference spectra required by CORGAM had been
collected in an identical manner (Ec-68).

Due to the special purpose of cereal analysis problems, the reference
spectra contained in the library of the code is formed from those spectra
of the elements contained in agricultural samples. These reference isotopes
are: ^{24}Na, ^{42}K, ^{56}Mn, ^{38}Cl, ^{80}Br, ^{82}Br, ^{49}Ca, ^{28}Al, ^{27}Mg, ^{64}Cu, ^{128}I, and ^{37}S. But it is
possible to replace the reference spectra by the ones needed for the ana-
lysis of other mixtures. It should be remembered that the reference data
collection and that of the complex one should be done in identical conditions

START

Select:
1. Reference Spectra
2. Level of Significance
   a) Null Hypothesis, H_o
   b) Quality of fit

Calculate:
1. Intensity Coefficients
2. Student's t Values
3. Quality of fit

Compare:
Calculated Quality of fit to the preselected Level of Significance

$>$

Calculate:
Correct Error Variances for Variances of Intensity Coefficients and Independent Variables

$\leq$

Compare:
Calculated Student's t Values to the preselected Level of Significance for H_o

$<$

Remove:
Nonsignificant Reference Spectra

STOP

Figure: 3.1- Outline of correlation algorithm for resolution of gamma spectra.

3.3- EXPERIMENTAL PROCEDURE OF CORGAM

Previuos use of CORGAM was for the routine analysis of agricultural samples.In order to perform this analysis, the experimental procedure used is given in this section (Ec-68).The input data of the same experiment is used to run the program.The listing of the input data and that of the output obtained from the sample problem run are given in the appendix L.During the data collection of the sample problem the following equipment were used.

1. Shielded counting arrangement:A lead shielded counting cavity with interior dimensions of 24" x 24" x 30" was constructed of 2" x 4" x 8" lead bricks, with exterior walls 4" thick, and top and bottom 2" thick.The interior of the cavity was lined with 0.025" thick cadmium sheet followed by 0.025" thick copper sheet.Shielded counting cavity and wall construction details are illustrated in figure 3.2.By using this cavity background is reduced by a factor of 20 % .

2. Detector assembly:The scintillation crystal used is Harshaw 3"x3" NaI(Tl), solid type crystal,Model 12512,serial CC362 integral line.It uses an RCA 8054 photomultiplier tube,the resolution of the crystal is 8.07 %.

3. Preamplifiers:Two main purposes of a preamplifier are to serve an impedance matching and an amplification function.The preamplifier used in this experiment was TMC model DS-13 with a gain of approximately 2.0.

4. Multichannel analyzer:The multichannel analyzer is used to sort and store voltage pulses according to their respective heights.The pulses are sorted into differential pulse height units,i.e.,from v_o to v_o v.That function is carried out by converting the pulse height to time and measuring the elapsed time from pulse base to pulse height.The analyzer used in this experiment was the TMC 4096 multiparameter system.

5. Neutron source:KSU TRIGA Mark II nuclear reactor was used as a source of thermal neutrons.A typical irradiation for neutron activation analysis is made in either the pneumatic transfer unit or in the rotary specimen rack.In table 3.2 the approximate neutron flux values per watt of power at those two locations are compared.

The block diagram of the NAA instrumentation system is shown in figure 3.3.

6.Reference spectra:Spectroscopically pure compounds were irradiated to collect the reference spectra used in this experiment.Table 3.3 is a compilation of information about each of these compounds.

Neutron Energy	Pneumatic transfer unit n/cm^2-sec-watt	Rotary specimen rack n/cm^2-sec-watt
Thermal	1.7×10^7	7.2×10^6
Fast	1.4×10^7	6.0×10^6

Table: 3.2- Neutron flux levels for KSU TRIGA Mark II nuclear reactor (EG-68)
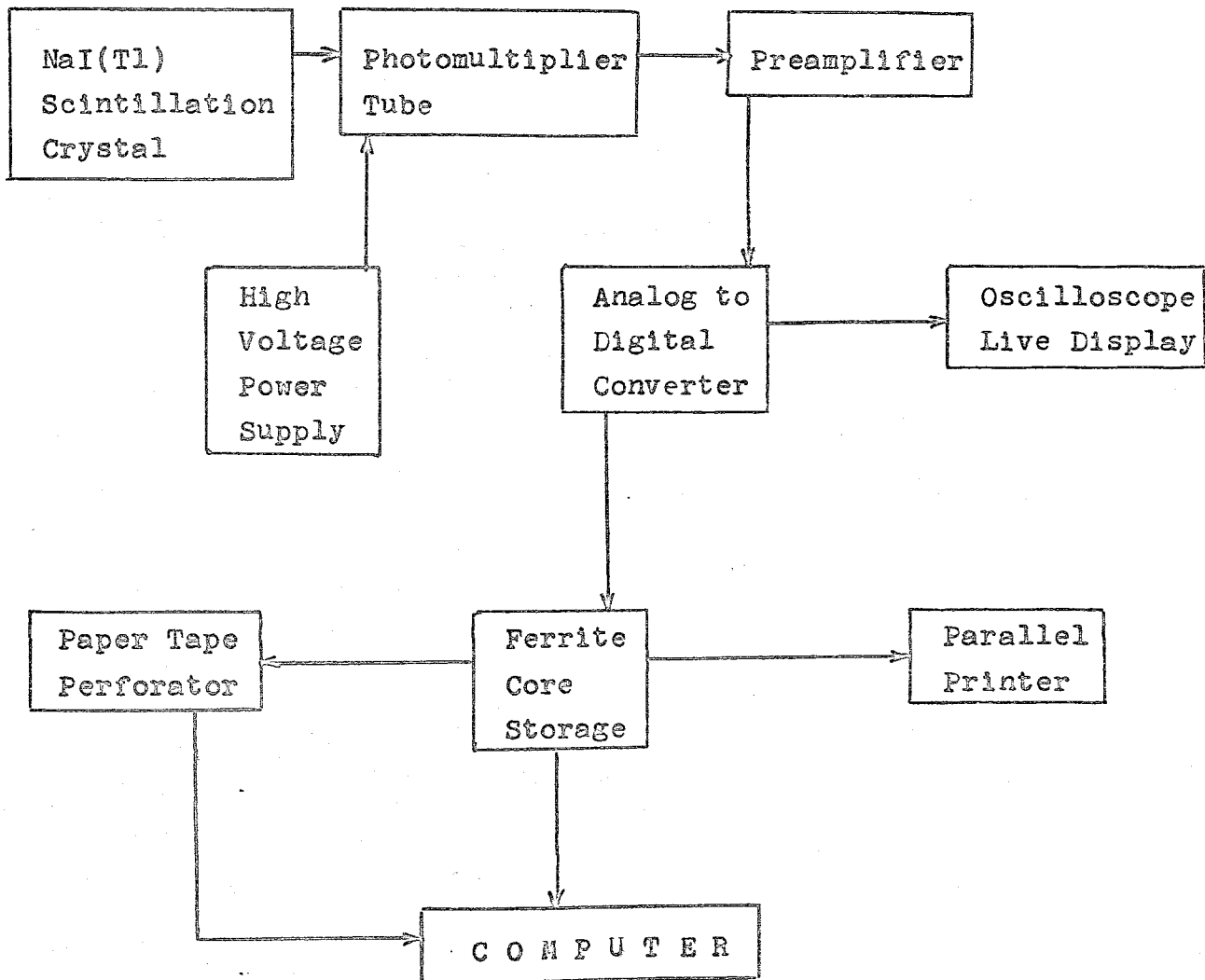
Figure: 3.3- Block Diagram of the NAA instrumentation system.

Table: 3.3- Reference spectra information.(Ec-68)

Element	Chemical Form	%H_2O Hydration	Reference isotope	Half Life (min)	Irradiation Policy "	Weight (gm)
Na	Na_2CO_3	6.8	Na^{24}	900.0	1-4-2-10	0.229
K	K_2CO_3	5.1	K^{42}	744.0	4-4-5-10	0.299
Mn	metal	0.0	Mn^{56}	154.8	2-4-2-0.1	0.0806
Cl	NH_4Cl	0.0	Cl^{38}	37.3	2-5-2-50	0.0130
Br	NH_4Br	0.0	Br^{80}	18.0	2-65-2-90	
			Br^{82}	2118.0	2-1707-10	0.0304
Ca	$CaCO_3$	1.4	Ca^{49}	8.8	2-5-2-10	0.194
Al	Al_2O_3	3.9	Al^{28}	2.3	1-12-2-10	0.0628
Mg	MgO	5.5	Mg^{27}	9.5	2-5-2-10	0.0788
Cu	powder	0.0	Cu^{64}	774.0	1-112-3-10	0.0321
I	KI	0.3	I^{128}	25.0	2-5-2-50	0.0252
S	powder	0.0	S^{37}	5.1	2-5-2-50	0.2064

" The first number is the irradiation time in minutes.The second number is the decay time in minutes.The third number is the counting time in minutes.The fourth number is the reactor power level in kilowatts.

The reference spectra were collected using the following procedure: A small amount ($\leqslant$ 1.0 gram) of each spectroscopically pure reference compound,and a small amount of copper powder were irradiated in the rotary specimen rack (RSR) of the KSU TRIGA Mark II nuclear reactor for the times iven in table 3.3.After the respective times had elapsed,the reference spect ra were collected for the counting time given in table 3.3,using the solid " x3" NaI(Tl) scintillation crystal.
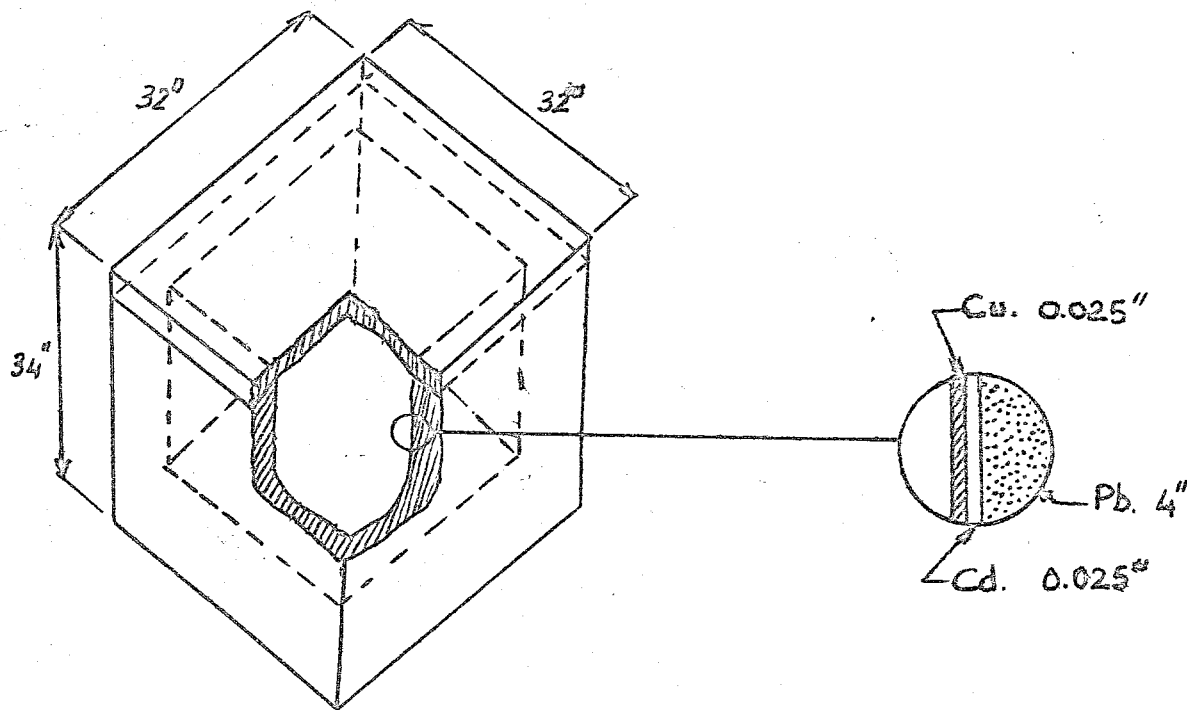
Figure: 3.2- Shielded counting cavity dimensions and details (Ec-68).

Instabilities in the spectrometer system used to collect the gamma-ray spectra can cause shifts to occur in these spectra.To compensate for these inconsistencies, the gamma-ray photopeaks of the spectra were fit to a Gaussian function using a linearized least squares method.The mid-point corresponding to the gamma-ray energy was calculated from the relation, $X_O = E/G$ where E is the gamma-ray energy in MeV.If a reference spectrum contains more than one gamma-ray photopeak,these mid-channel values were used to calculate the slope and intercept of the relation, $E a_O G X_O$,where E is the gamma-ray energy in MeV and X_O is the mid-channel value of the photopeak.However,if the reference spectrum contains only one photopeak,the intercept was assumed to be zero. Using these parameters,each spectrum was shifted to a slope and intercept of 14.5 keV/ch and zero,respectively.Each of the gamma-ray photopeaks in the shifted spectra was fitted to a Gaussian function (Ec-68).

A more detailed description of the procedure and various applications performed by using CORGAM can be found in the reference Ec-68.

4. DISCUSSION AND CONCLUSION

The importance of neutron activation analysis was mentioned in the previous subsections. It is also mentioned that the determination of the micro constituents of a complex sample was possible down to the ppm (parts per million) level. In the study of the principles of NAA, it is noticed that the interaction of gamma radiation with the detector material was very important. The gamma-rays resulting from the decay of activated nuclei, interact with the detector. If the material of the detector is a phosphor, scintillations are produced in the phosphor resulting from the interaction of the incoming photons with the detector material. These scintillations are transformed into electrical signals by the photomultiplier tube. The signals are then amlified measured and recorded by the use of proper electronic equipments. The most widely used electronic equipment is a multichannel analyzer, which gives a distribution of the incoming photons with respect to their energies. This amlitude versus energy distribution of the photons is called the gamma-ray spectrum of the activated nuclei. Due to the character of the interactions of gamma-rays with a particular scintillation crystal, produces a unique gamma-ray spectrum. The analysis of this spectrum by the methods described in this work, gives the necessary information about the nature and the concentration of the constituents of the complex sample. Among the methods used in common NAA work, the correlation algorithm is found to be the best method for the resolution of gamma-ray spectra.

A predesigned computer code which uses the correlation algorithm in the unfolding procedure of a complex gamma-ray spectrum is also analyzed. In this analysis it is observed that the program is restricted to a problem of 400 channels and 15 reference spectra. There would be no difficulty in expanding this to as many as 4096 channels. However due to the accuracy desired in the inversion procedure, the number of reference isotopes is limited. CORGAM is a novel method of unfolding complex gamma-ray spectra because only reference spectra that have intensity coefficients which are significant at a preselected level are retained in the output and the variance calculations include contributions from both the reference and comlex spectra. The large computing time required by the NAA can be eliminated by the use of a computer program. A typical analysis, involving 256 channels and 14 reference spectra, requires less than 1 minute of execution time on an IBM 360/50. Although the computer memory requirements are large for the correlation

algorithm as it was programmed for the IBM 360/50,it is possible to segment the program for adaptation to a smaller computer.In order to use this program in NAA,changes should be made on the reference spectra and on the flux reference spectra according to the laboratory conditions.The choice of the spectrometr system affects the results in various ways.When a NaI(Tl) crystal is used the interferences of the various reference spectra became significant, Use of a Ge(Li) semiconductor detector eliminates these interferences to a desired level.

Presently the code contains eleven reference spectra in its library, if needed these spectra can be changed by the ones required for a specific analysis.Since the number of reference spectra is limited by 15 isotopes,at each special problem,need may arise to change the reference library.It is concluded that this procedure was very time consuming when the spectometer system is not branched to the computer where the program will be run.

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A P P E N D I C E S

<center>APPENDIX A</center>

-PROPERTIES OF ESTIMATORS

The estimate of the intensity coefficients (concentrations) of the equation 3.14 have the following properties;

a) Unbiased (Gr-61): An estimator,a,for the parameter α is defined as an unbiased estimator of α if

$$E(a) = \alpha \qquad (A-1)$$

where E represents the mathematical expectation. The mathematical expectation is defined by the following theorem (Ho-63).

Theorem: Let $\underline{x}$ be a random variable with density $f(x)$. The expected value of a function u of the random variable $\underline{x}$ is,

$$E(u(x)) = \sum_i u(x_i) \, f(x_i) \qquad (A-2)$$

if $\underline{x}$ is descrete, and

$$E(u(\underline{x})) = \int_{-\infty}^{\infty} u(x) \, f(x) \, dx \qquad (A-3)$$

if $\underline{x}$ is continuous.

Therefore,the mathematical expectation is just the mean value of the function u of the random variable $\underline{x}$.

b) Minimum variance(Gr-61): An estimator,a,is defined to be the minimum variance estimator of the parameter α if

$$E((a-E(a))^2) \leqslant E((a^o-E(a^o))^2) \qquad (A-4)$$

The term $E((a-E(a))^2)$ is defined to be the variance of the parameter α

c) Sufficiency (Mo-63): Let $f(\underline{x}, \alpha)$ be a joint frequency function involving the parameter α and the random variable $\underline{x}$,n in number. Let $a_1 \ h_1(\underline{x})$, $a_2 \ h_2(\underline{x})$ ....$a_k \ h_k(\underline{x})$ be a set of statistics and $a_1^o \ h_1^o(\underline{x})$, $a_2^o \ h_2^o(\underline{x})$ ....$a_k^o \ h_k^o(\underline{x})$ be any other set set of estimators which are not functions of a_1, a_2, a_k. If $g(\underline{a}^o/\underline{a})$, the conditional density function of $\underline{a}^o$ given $\underline{a}$,does not involve α ,the set $\underline{a}$ is called a set of sufficient statistics. This means that "all the information" contained in the n values of $\underline{x}$ is given

by the k parameters $\underline{a}$ where $k < n$.

d) Cconsistency (Mo-63): If $\underline{a}$ is a sequence of estimators of α, they are simple consistent estimators, if for every $\varepsilon > 0$

$$\lim_{n \to \infty} P(|\bar{a}_n - \alpha| \leq \varepsilon) = 1 \qquad \text{(A-5)}$$

Further, the estimators, $\underline{a}$, are squared error consistent estimators of α, if

$$\lim_{n \to \infty} \left\{ E((\bar{a}_n - \alpha)^2) - \frac{1}{n} \sum_i (a_i - \alpha)^2 \right\} = 0 \qquad \text{(A-6)}$$

where

$$\bar{a}_n = \frac{1}{n} \sum_i a_i$$

Squared error consistency imlies that both the bias and variance of $\underline{a}$ approach zero as the number of sample points increase.

e) Efficiency (Br-65): efficiency of an estimator is defined to be the ratio of the variance of the minimum variance estimators to the variance of the estimator in question. Thus, minimum variance estimators are said to be efficient estimators .

APPENDIX B

-THE LEAST SQUARES METHOD

The method is used to determine the intensity coefficients for the NAA problem. To illustrates the method, consider a set of n points, (x,y). The points are assumed to be related by the linear hypothesis (Gr-74):

$$y_i = B_o + B_1 x_i + e_i \, , \qquad i = 1,2,3,\ldots,n \tag{B-1}$$

where e_i is the deviation at point i of the estimated value, from its observed value, y_i, B_o, B_1 are the true values of the intercept and slope, respectively. The estimators, b_o and b_1, for B_o and B_1 can be obtained by minimizing the sum of the squared errors;

$$S = \sum_{i=1}^{n} e_i^2 = \sum_{i=1}^{n} (y_i - (B_o + B_1 x_i))^2 \tag{B-2}$$

S is minimized by differentiating with respect to B_o, and B_1 and equating the results to zero. Also, b_o and b_1, the estimators, are substituted for B_o and B_1. The resulting equations are;

$$\sum_{i=1}^{n} (y_i - (b_o + b_1 x_i)) = 0 \tag{B-3}$$

$$\sum_{i=1}^{n} \left\{ x_i (y_i - (b_o + b_1 x_i)) \right\} = 0 \tag{B-4}$$

Equations B-3 and B-4 can be rearranged into a form called the normal equations.

$$b_o n + b_1 \sum_{i=1}^{n} x_i = \sum_{i=1}^{n} y_i \tag{B-5}$$

$$b_o \sum_{i=1}^{n} x_i + b_1 \sum_{i=1}^{n} x_i^2 = \sum_{i=1}^{n} y_i x_i \tag{B-6}$$

Solving equations B-5 and B-6 for b_o and b_1, results in

$$b_1 = \frac{\sum_{i=1}^{n} x_i y_i - ((\sum_{i=1}^{n} x_i)(\sum_{i=1}^{n} y_i))/n}{\sum_{i=1}^{n} x_i^2 - (\sum_{i=1}^{n} x_i)^2/n} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{B-7}$$

$$b_o = \bar{y} - b_1 \bar{x} \tag{B-8}$$

where,

$$\bar{y} = (\sum_{i=1}^{n} y_i)/n \quad , \qquad \bar{x} = (\sum_{i=1}^{n} x_i)/n.$$

Equation B-1 can be rewritten in terms of the estimator, b_1, and the mean value $\bar{x}$ and $\bar{y}$, through the use of equation B-8.

$$y_i = \bar{y} + b_1(x_i + \bar{x}) \quad , \quad i = 1,2,3,\ldots,n \tag{B-9}$$

Equation B-9 can be rewritten in matrix form as,

$$\underline{Y} = \underline{X}b_1 \quad , \tag{B-10}$$

where $\underline{Y} = (y-\bar{y}) = (n \times 1)$ vector of the dependent values

$\underline{X} = (x-\bar{x}) = (n \times m)$ matrix of the independent variables.

In matrix form, the linear hypothesis model, equation B-1, is more appropriately written as,

$$\underline{Y} = \underline{B}'\underline{X}' + \underline{e} \tag{B-11}$$

where $\underline{X}'$ is the transpose of the $(n \times m)$ matrix X

$\underline{B}'$ is the transpose of the $(m \times 1)$ solution vector B

$\underline{e}$ is the $(n \times 1)$ vector of deviations.

More often equation B-11 is written in the following form:

$$\underline{Y} = \underline{X}B + \underline{e} \tag{B-12}$$

APPENDIX   C

-CURVE FITTING METHODS

The following method was used to fit the photopeaks to a Gaussian function (Ec-68).

First the photopeaks were assumed to be pure Gaussian, i.e.,

$$y_i = y_o \exp(-(x_i-x_o)^2/b_o) , \qquad (C-1)$$

y_i is the counts in channel i of a photopeak,

y_o is the count corresponding to channel x_o,

x_o is the mean channel of the Gaussian function

x_i is the channel number

$b_o = 2\sigma^2,$

σ^2 is the variance of the Gaussian function.

Equation C-1 is non linear and must be linearized to apply the principle of least squares. The logarithm of equation C-1 yields a linear form.

$$\ln y_i = \ln y_o - \frac{x_o^2}{b_o} + \frac{2x_o}{b_o} x_i - \frac{1}{b_o} x_i^2 \qquad (C-2)$$

Equation C-2 can be rewritten in terms of new variables,

$$z_i = a_1 + a_2 x_i + a_3 x_i^2 \qquad (C-3)$$

where,

$$z_i \equiv \ln y_i ,$$

$$a_1 \equiv \ln y_o - \frac{x_o^2}{b_o} , \qquad a_2 \equiv \frac{2x_o}{b_o} .$$

$$a_3 \equiv -\frac{1}{b_o}$$

The principle of least squares applied to equation C-3 yields the following matrix equation

$$a = (X'WX)^{-1} (X'WZ) , \qquad (C-4)$$

where   a is a (3x1) vector of the coefficients a_1, a_2 and a_3,

X is a (nx3) matrix whose first column is composed of all unity values
the second column is composed of the x_i values, and the third column is

composed of the x_2 values

    X' is the transpose of X,

    Z is a (nx1) vector of the z_i values,

    W is a (nxn) diagonal weighting matrix whose elements are the inverse of the variances of the z_i values,

    n is the number of data points.

The variance of z_i can be obtained by

$$\sigma^2(z_i) = \frac{1}{y_i^2} \sigma^2(y_i) = \frac{1}{y_i} \tag{C-5}$$

It should be noted that by applying the principle of least squares to equation C-3 instead of to equation C-1 the minimum total squared deviation is,

$$S_D = \sum_{i=1}^{n} \left\{ y_i - y_o \exp\left[-(x_i - x_o)^2 / b_o\right] \right\}^2 \tag{C-6}$$

The desired minimum total deviation is,

$$S_L = \sum_{i=1}^{n} \left[\ln y_i - \left(\ln y_o - \frac{x_o^2}{b_o} + \frac{2 x_o}{b_o} x_i - \frac{1}{b_o} x_i^2 \right) \right]^2 \tag{C-7}$$

Minimizing S_L does not guarantee a minimum for S_D. To minimize S_D requires an iterative technique which employs a Taylor's series expansion and can result in unstable solutions for cases with variations in the data. In addition this method requires a significantly longer amount of computation time.

    Variance values of y_o, x_o, and b_o, could be obtained by

$$\sigma^2(y_o) = \left[C_{1,1} + \frac{a_2^2}{4 a_3^2} \left(C_{2,2} + \frac{a_2^2}{4 a_3^2} C_{3,3} \right) \right] \exp\left[2\left(a_1 - \frac{a_2^2}{4 a_3} \right) \right] \tag{C-8}$$

$$\sigma^2(x_o) = \frac{1}{4 a_3^2} \left[C_{2,2} + \left(\frac{a_2}{a_3} \right)^2 C_{3,3} \right] \tag{C-9}$$

$$\sigma^2(b_o) = C_{3,3} / a_3^4 , \tag{C-10}$$

where,

    a_1, a_2, a_3, are the elements of the vector a, and $C_{1,1}$, $C_{2,2}$, $C_{3,3}$ are the diagonal elements of the $(X'WX)^{-1}$ matrix. Since the y_o value is just a normalization term, it could also be calculated by minimizing S_D after x_o and b_o were obtained by minimizing S_L. This method yielded lower variance values for y_o (Gr-74). Hence, y_o and (y_o) were calculated from,

$$y_0 = \sum_{i=1}^{n} w_i \, y_i \, k_i \Big/ \sum_{i=1}^{n} w_i \, k_i^2 , \tag{C-11}$$

$$\sigma^2(y_0) = \left[\sum_{i=1}^{n} w_i \, k_i^2 \right]^{-1} \tag{C-12}$$

where

n is the number of data points used in the fit,

$k_i = \exp(-(x_i - x_0)^2 / b_0)$

In deriving equation C-12 it was assumed that $w_i = \dfrac{1}{y_i}$.

APPENDIX   D

-LAGRANGIAN INTERPOLATION

This interpolation method is used in the subprogram REFIN, to inter-polate between the decay spectra of a reference isotope.

The method is based on polynomial interpolating functions (Ak-77). Assume that a function y f(x) is given at (n-1) points, say x , x , x ,...x , and determine a polynomial F(x) of degree n or less such that

$$F(x_i) = f(x_i) \qquad i = 0,1,2,....,n \qquad \text{(D-1)}$$

It may be proved that the polynomial exists and it is unique. For this purpose two alternative proofs will be given.

Proof 1:

Let F(x) function is written as

$$F(x) = L_0 y_0 + L_1 y_1 + ...L_n y_n \qquad \text{(D-2)}$$

where

$$y_0 = f(x_0) \ , \ y_1 = f(x_1) \ ,........ \ y_n = f(x_n) \qquad \text{(D-3)}$$

and

$$L_i(x) = \prod_{\substack{j=o \\ j \neq i}}^{n} \left(\frac{x - x_j}{x_i - x_j} \right) \qquad i = 0,1,2,.... \ n \qquad \text{(D-4)}$$

It is clear that each $L_i(x)$ term is a polynomial of degree n or less and rewritting it explicitly as

$$L_i(x) = \frac{(x-x_0)(x-x_1)(x-x_2).....(x-x_{i-1})(x-x_{i+1})....(x-x_n)}{(x_i-x_0)(x_i-x_1)(x_i-x_2).....(x_i-x_{i-1})(x_i-x_{i+1})....(x_i-x_n)} \qquad \text{(D-5)}$$

it is obvious that $f(x_j) = F(x_j)$ because for $j \neq i$, where $j=0,1,...,n$, all $L_i(x_j)$ terms are zero. For $j=i$ case $L_i(x_j)=1$ and therefore,

$$F(x_i) = L_0(x_i)y_0 + L_1(x_i)y_1 + L_2(x_i)y_2 + ...L_n(x_i)y_n \qquad \text{(D-6)}$$

becomes $F(x_i) = y_i$ where $y_i = f(x_i)$ $\qquad$ (D-7)

Proof 2:

An alternative method to determine the interpolating polynomial will be given using the method of undetermined coefficients.

(a) being any convenient value, then

$$F(x_1) = C_0(x-a)^n + C_1(x-a)^{n-1} + \ldots \ldots C_n \tag{D-8}$$

The coefficients $C_0, C_1, \ldots, C_n$ will be such that

$$F(x_i) = f(x_i) \quad or \quad F(x_i) = y_i \tag{D-9}$$

is satisfied. Obviously, C_k coefficients must satisfy the following system of linear algebraic equations,

$$C_0(x_0-a)^n + C_1(x_0-a)^{n-1} + \ldots \ldots + C_n = y_0$$
$$C_0(x_1-a)^n + C_1(x_1-a)^{n-1} + \ldots \ldots + C_n = y_1$$
$$\vdots$$
$$C_0(x_n-a)^n + C_1(x_n-a)^{n-1} + \ldots \ldots + C_n = y_n \tag{D-10}$$

This system of n-1 equations in terms of n-1 unknowns will have a solution if the coefficient matrix is nonsingular. The determinant of the coefficient matrix, which is known as Vandermonde determinant, is written as

$$\Delta = \begin{vmatrix} (x_0-a)^n & (x_0-a)^{n-1} & \ldots \ldots & (x_0-a) & 1 \\ (x_1-a)^n & (x_1-a)^{n-1} & \ldots \ldots & (x_1-a) & 1 \\ \vdots & & \vdots & & \vdots \\ (x_n-a)^n & (x_n-a)^{n-1} & \ldots \ldots & (x_n-a) & 1 \end{vmatrix} \tag{D-11}$$

and its value is given as

$$\Delta = \prod_{\substack{i,j=0 \\ i<j}}^{n} (x_i - x_j) \tag{D-12}$$

Since x_1 are distinct, it follows that $\Delta \neq 0$ and C_k can be uniquely determined. Quite often in computations a=0 is taken (Jo-74).

APPENDIX E

-DETERMINANT EVALUATION BY CHIO'S METHOD (PIVOTAL CONDENSATION)

This method is used in the subprogram DET in order to evaluate the determinant of the $(X'WX)$ matrix.

This method continuously reduces the order of the determinant by one, using a series of subtractions (Ak-77). For the explanation of the method suppose a $(4,4)$ matrix A is given.

$$|A| = a_{11} \begin{vmatrix} 1 & a'_{12} & a'_{13} & a'_{14} \\ a_{21} & a_{22} & a_{23} & a_{24} \\ a_{31} & a_{32} & a_{33} & a_{54} \\ a_{41} & a_{42} & a_{43} & a_{44} \end{vmatrix} = a_{11} \begin{vmatrix} 1 & 0 & 0 & 0 \\ a_{21} & a''_{22} & a''_{23} & a''_{24} \\ a_{31} & a''_{32} & a''_{33} & a''_{34} \\ a_{41} & a''_{42} & a''_{43} & a''_{44} \end{vmatrix}$$

$$\qquad\qquad\qquad\qquad\qquad\qquad 1 \qquad 2 \qquad 3$$

where

$$a'_{12} = \frac{a_{12}}{a_{11}} \quad , \quad a'_{13} = \frac{a_{13}}{a_{11}} \quad , \quad a'_{14} = \frac{a_{14}}{a_{11}}$$

in the second step, performing the following operations,

$$1: (2^{nd}\ col.) - a'_{12} \times (1^{st}\ col.)$$
$$2: (3^{rd}\ col.) - a'_{13} \times (1^{st}\ col.)$$
$$3: (4^{th}\ col.) - a'_{14} \times (1^{st}\ col.) \qquad\qquad \text{yields a reduction in the}$$

order of the determinant;

$$|A| = a_{11} \begin{vmatrix} a''_{22} & a''_{23} & a''_{24} \\ a''_{32} & a''_{33} & a''_{34} \\ a''_{42} & a''_{43} & a''_{44} \end{vmatrix} = a_{11}\,a''_{22} \begin{vmatrix} 1 & a'''_{23} & a'''_{24} \\ a''_{32} & a''_{33} & a''_{34} \\ a''_{42} & a''_{43} & a''_{44} \end{vmatrix} = a_{11}\,a''_{22} \begin{vmatrix} 1 & 0 & 0 \\ a''_{32} & a'''_{33} & a'''_{34} \\ a''_{42} & a'''_{43} & a'''_{44} \end{vmatrix}$$

$$1: (2^{nd}\ col.) - a'''_{23} \times (1^{st}\ col.)$$
$$2: (3^{rd}\ col.) - a'''_{24} \times (1^{st}\ col.)$$

$$|A| = a_{11}\,a''_{22} \begin{vmatrix} a'''_{33} & a'''_{34} \\ a'''_{43} & a'''_{44} \end{vmatrix} = a_{11} \cdot a''_{22} \cdot \left[\left(a'''_{33} \times a''''_{44} \right) - \left(a'''_{43} \times a'''_{34} \right) \right]$$

The procedure is repeated till a $(2,2)$ determinant is finally reached. (Yc-73, Ay-62).

APPENDIX F

--DESCRIPTION OF THE PROGRAMS

CORGAM is the main program through which the flow of the program is controlled.This program is used to:
1. Read the program flow parameters.
2. Define many of the data parameters.
3. Read the input data which describes the experimental conditions, such as irradiation time,counting times,etc.
4. Read the complex spectrum,i.e.,the spectrum to be analyzed.
5. Subtract background from the complex spectrum,normalize it,and shift it to compensate for electronic instabilities in the MCA.
6. Calculate the irradiation and decay time correction factors.
7. Form the $(X'WX)$ matrix.
8. Calculate the concentration estimators.
9. Delete any and all non-significant reference isotopes.
10. Print or punch the output information.

The following 19 subprograms are called by CORGAM,their description are given in the following pages,and they are listed in order called.

1. INIT
2. PHOTO
3. SMINV
4. INDEX
5. SHIFT
6. SHIFTS
7. WATE
8. REFS
9. REFIN
10. XFORM
11. PEAKS
12. SAVE
13. DET
14. DELETE
15. STAT
16. WRIT

17. CHI
18. VARNCE
19. WRIT1

The following is the listing of the subprograms called by CORGAM. The description of the subprograms are also given together with the variables used and their options.

1. INIT:

This subprogram is used to initialize the irradiation and decay correction factors and many of the program control parameters.

SUBROUTINE INIT (NITER,RAT,SAV,C,ISOCHN,MODE,NBKGD,NUBKG,NSHFT,NPK,LPP,NORM, NCTIN,NAREA,NCHCU,NCULL,NCUUL,NRHO,NUMVAR,NVAR,NREFS,ITER,NR,NW,LOCHN,NHICHN, NCHAN,MC,MVAR,T,AREA,BKGTIM,TIMIRR,FHRL,UP,XNCOM)

DIMENSION C(15)

NITER: Number of iterations used in variance calculations

RAT: Correction factor

SAV: Correction factor

C(I): Correction factor for the Ith reference isotope, if -1.0 is entered for C(I) value, the Ith isotope is deleted from the analysis.

ISOCHN: Number of channels in the complex spectrum.

MODE: 1 Read by 5E14.8 format

   2 Read by 6X,12F6.0,2X format

NBKGD: 0 no background subtraction

   Other will subtract background

NUBKG: 0 no new background will be read

   Other, a new background will be read

NSHFT: 0, no spectrum shifting

   Other, will shift spectrum

NPK: Number of peaks in complex spectrum used in shifting

LPP: Index of peak used in shifting ratio

NORM: 0, no normalization of complex spectrum is needed

   Other, normalize the complex spectrum

NCTIN: 0, read precalculated correction factors

   Other, read unity (or less than zero for deletion)

NAREA: 0, raed photopeak area for copper reference

   1, calculate pp area for Cu ref., read Cu spectrum (read any)

   2, use same area as previous spectrum.

NCHCU: Number of channels in Cu reference spectrum.

NCULL: Lower fit limit on Cu reference photopeak.

NCUUL: Upper fit limit on Cu reference photopeak.

NRHO: 0,will not punch shifted output

      Other,will punch shifted output

NUMVAR: Number of variances to be avaraged

NVAR: 1,read variance by 5E14.8 format

      2,variance:1.0

      3,variance:RHO

      4,use variance previously read

NREFS: 0,new set of reference spectra are read

      1,no new reference spectra are to be read

ITER: Maximum number of iterations on variance

NR: 0,calculate average weight variance from the long way

    Other, ratio:YAVE/YAVEAEVE

NW: 0,will not punch shifted output for reference spectra

    Other,will punch shifted output for reference spectra

LOCHN: Lower channel of least squares fit

NHICHN: Upper channel of least squares fit

NCHAN: Number of channel in variance spectrum if variance are to be read

MC: Number of reference spectra which have a set of decay spectra.These

    spectra must be in order and they must be the first of the reference

    spectra to be read in.

MVAR: 0,variance of reference spectrum:reference spectrum

    Other,read variance of reference spectrum

T: Student'S t value for null hypothesis test

AREA: Copper reference photopeak normalized area

BKGTIM: Counting time of background (minute)

TIMIRR: Complex sample irradiation time (minute)

FRHL: Flux reference half-life (minute)

UP: U_p factor of Chi-squared test (confidence interval factor)

XNCDM: Complex spectrum normalization constant.

        This subprogram is read only for the complex spectrum whose data are not given in the beguinning of the main program.Generally the first complex spectrum data is given in DATA statement and in NAMELIST.The complex spectra variables following the first one are initialized by this subprogram.

2. PHOTO:

This program is used to fit the photopeak data of a spectrum to a linearized form of the Gaussian function. The fitting technique is discussed in the Appendix C.

```
SUBROUTINE PHOTO (RES,XO,IPPLL,IPPUL,EPP,AREA)
DIMENSION B(3),Q(15,15),RES(400),RE(3),BZ(60),C(10)
```

RES(I): Counts registered at the Ith channel of the flux reference spectrum.
XO: x_o (x sub o) of the equation C-1 of appendix C.
IPPLL: NCULL(defined in INIT)
IPPUL: NCUUL(defined in INIT)
EPP: Midpoint energy of the photopeak of interest (MeV).
AREA: defined in INIT

3. SMINV:

This subprogram is the scientific subroutine designed for the IBM 360 to invert symmetric matrices. It is modified by the author by its UNIVAC version in order to use in Boğaziçi University computer.

```
SUBROUTINE SMINV (R,N)
DIMENSION A(230),R(15,15)
```

R(I,J): I^{th} row, J^{th} coloumn element of the matrix
N: Order of the matrix

The subprogram is used to obtain the inverse of a symmetry matrix A of order N. Only the upper triangular part of A is stored. On exit the inverse replaces A in storage. The inverse matrix is found by succesive congruent transformations to obtain the diagonal. Inverting the diagonal elements and performing the congruent transformations in reverse gives the inverse matrix. In this code A is the (X'WX) matrix.

4. INDEX:

This subprogram is apart of the subroutine SMINV and is used to store a two-dimentional matrix as a row vector. It is applicable only for symmetrical matrices. It allows reference to a two-dimentional matrix with subscripts (I,J) while the matrix is stored as a vector.

FUNCTION INDEX (I8,J8,N)
I8: Row of matrix
J8: Coloumn of matrix
N: Order of matrix (maximum value 15)

While a matrix of order N has NxN elements, the same matrix stored as a vector will have $(N^2+N)/2$ elements, provided that the matrix is symmetric In this way storage space is reduced.

5. SHIFT:

This program is used to calculate the input parameters to SHIFTS.

SUBROUTINE SHIFT (NCHN,NPK,LPP,NWRITE,Y,PO)

NCHN: ISOCHN (defined in INIT)
NPK: defined in INIT
LPP: defined in INIT
NWRITE: NRHO (defined in INIT)
Y(I): RHO(I), counts registered at the Ith channel of the complex spectrum
    (I_{max}:400, i.e., up to 400 channels can be used).
PO: Identification number of the spectrum to be shifted.

6. SHIFTS:

This program is used to shift a spectrum to a new gain and baseline, hence it will compensate for electronic instabilities in the MCA.

SUBROUTINE SHIFTS (SPECT,S,RATIO,NCHN,NCHN2,BLSHFT)
DIMENSION SPECT(400),S(400)

SPECT(I): Counts registered at the Ith channel of the unshifted spectrum.
S(I): Counts registered at the Ith channel of the shifted spectrum by using
    SPECT(I).
RATIO: Shifting ratio
NCHN:ISOCHN (defined in INIT),unshifted channel number.
NCHN2: The shifted new channel number.
BLSHFT: Baseline shift.

7. WATE:

This program is used to establish the original form of the weighting matrix. It calculates or reads the weight factors and raed or set variances using (A) as storage.

SUBROUTINE WATE (NVAR,NUMVAR,NCHAN,RHO,XNCOM,III,OMG,A',RES,ISOCHN)
DIMENSION RES(400),RHO(400),OMG(400),A(400)

NVAR: Defined in INIT
NUMVAR: Defined in INIT
NCHAN: Defined in INIT
RHO(I): Counts registered at the Ith channel of the complex spectrum.
XNCOM: Defined in INIT
III: Identification number of the complex spectrum (if several complex spectra
     are to be analyzed.
OMG(I): I^{th} element of the variance vector.
A(I): I^{th} element of the vector X in $(X^o WX)$ matrix.
RES(I): Defined in PHOTO
ISOCHN: Defined in INIT.

8. REFS:

This program is used to read all pertinent reference spectra concerning each spectrum. Options are provided for each spectrum to have a background subtraction, to be normalized, and to be corrected for decay. In addition, a set of reference spectra (up to five) for an element which upon irradiation produces several non separable isotopes, such as Br Br^{80}, Br^{82}, may be read in. This program uses these data by interpolation to obtain the reference spectrum at the decay time of the complex spectrum.

SUBROUTINE REFS (NISO,NHICHN,ISO,XNORM,O,AT,BKG,NW,DECAY,COUNT,III,NFAC,
FRRHL,D,H,MC,NO,RHO,A)
DIMENSION ISO(15),H(15),D(15),XNORM(15),O(15),AT(400,15),BKG(400),RES(400),
P(15),CALC(400),NFAC(15),CT(400,15),T(5),C(5),RHO(400),A(400)

NISO: Number of reference isotopes used in the analysis of the complex spectrum
NHICHN: Defined in INIT
ISO(I): Number of channels in the Ith reference spectrum
XNORM: Normalization constant
O(I): Identification name of the reference spectrum

AT(I,J): Counts registered at the Ith channel of the Jth reference spectrum
BKG(I): Counts registered at the Ith channel of the background spectrum.
NW: Defined in INIT
DECAY: Decay time for complex spectrum (minute)
COUNT: Counting time for complex spectrum (minute)
III: Defined in WATE
NFAC(I): Decay time specification for the Ith reference isotope
FRRHL: Reference spectrum, flux reference isotope half-life (minute)
D(I): Irradiation time, in minutes, of reference sample spectrum
H(I): Half-life, in minutes, of reference isotope spectrum
MC: Defined in INIT
NO: Number of decay spectra of the reference isotope (max 5)
RHO(I): Defined in WATE
A(I): Defined in WATE

9. REFIN:

This program is used to interpolate, channel by channel between those spectra discussed in REFS, by Lagrangian method. The method is discussed in the appendix D.

SUBROUTINE REFIN (AT,III,T,C,CT,NO,M,DECAY,COUNT,ISO,RHO,A)
DIMENSION AT(400,15),CT(400,15),T(5),C(5),ISO(15),IS(15),RHO(400),A(400)

AT(I,J): Defined in REFS
III: Defined in REFS
T(K): Decay time in minutes of the Kth decay spectra of the Jth reference
C(K): Counting time in minutes of the Kth decay spectra of the Jth reference
CT(I,K): Counts registered at channel I of the Kth decay spectra for J^{th}
    reference isotope
NO: Defined in REFS
M: Tag name of the reference isotope
DECAY: Defined in REFS
COUNT: Defined in REFS
ISO(J): Defined in REFS
RHO(I): Defined in WATE
A(I): Defined in WATE

10. XFORM:

This program is used to form the (X'WX) matrix, its inverse, and the matrix correlation coefficients. A provision is included to evaluate the determinant of the matrix of correlation coefficients which is used as a measure of the efficiency for extracting the maximum information from the analysis problem. Further, the calculated identity matrix $(X'WX)^{-1}(X'WX)$ is formed and the error of average element can be found. Finally, the accuracy of the inverse matrix can be improved by an iteration method.

```
SUBROUTINE XFORM (NFORM,NISO,R,RI,MAXCON,P,O,LOCHN,NHICHN,A,AT,NCORR,NWRIT,
    NIDEN,NINTF,RII,BETA,THETA,OI,RHO,III)
DIMENSION R(15,15),RI(15,15),RII(15,15),P(15),O(15),A(400),AT(400),OI(15),
    Q(15,15),S(15,15),BETA(15),THETA(15),RHO(400)
```

NFORM: Specification for the $(X'WX)^{-1}$ matrix to be read or formed

NISO: Defined in REFS

R(I,J): The inverse cross product matrix $(X'WX)^{-1}$

RI(I,J): The cross product matrix (X'WX)

MAXCON: The remaining number of reference isotopes

P(I): Tag name of the Ith reference isotope

O(I): Defined in REFS

LOCHN: Defined in INIT

NHICHN: Defined in INIT

A(I): Defined in WATE

AT(I): Defined in REFS

NCORR: Control variable which specifies formation of correlation coefficients

NWRIT: Control variable which specifies writing options for the (X'WX) and its inverse

NIDEN: Control variable which specifies formation of identity matrix

NINTF: Control variable for interference calculation

RII(I,J): R(I,J), the $(X'WX)^{-1}$ matrix

BETA(J): Concentration estimators (ppm) of the Jth reference isotope

THETA(J): Interferences in percent

OI(J): Intermediate vector

RHO(I): Defined in WATE

III: Defined in REFS

11. PEAKS:

This program is used to select the data near each photo-peak which is to be used in the area-of-interest unfolding procedure.

SUBROUTINE PEAKS (AT,A,RHO,LOCHN,NHICHN,NISO,III)

AT(I,J): Defined in REFS
A(I): Defined in WATE
RHO(I): Defined in WATE
LOCHN: Defined in INIT
NHICHN: Defined in INIT
NISO: Defined in REFS
III: Defined in REFS

12. SAVE:

This program is used to store the original $(X'WX)^{-1}$ matrix and the corresponding reference spectra identification tags in order to allow stacking of the complex spectra

SUBROUTINE SAVE (NISO,O,OI,RI,RII)

NISO: Defined in REFS
O(J): The tag name of the reference spectrum
OI(J): O(J)
RI(I,J): The $(X'WX)^{-1}$ matrix
RII(I,J): RI(I,J)

13. DET:

This program is used to evaluate the determinant by pivotal condensation (Chio's method) of the matrix composed of the correlation coefficients of the $(X'WX)^{-1}$ matrix. The method is discussed in the appendix E.

SUBROUTINE DET (R,N,DETERM)

R: The matrix to be used $(X'WX)^{-1}$
N: Order of the matrix
DETERM: The determinant of the matrix R.

14. DELETE:

This program is used to delete from the analysis the reference spectra which are not significant at a pre-selected level

SUBROUTINE DELETE (NISO,REMOVE,ISOCHN,BETA,R,C,O,THETA,L)

NISO: Defined in REFS

REMOVE: Intermediate value for the reference isotope

ISOCHN: Defined in INIT

BETA(I): New concentration estimator for I^{th} reference isotope

R(I,J): The $(X'WX)^{-1}$ matrix

C(J): Defined in REFIN

O(J): Defined in REFS

THETA(J): Defined in XFORM

L: Tag name of the deleted isotope

15. STAT:

This program is used to calculate the standard deviations of the concentration estimators. In addition if some average weighting matrix is used in the analysis, this program is used to correct the standard deviations for this calculations.

SUBROUTINE STAT (RMOVE,BETA,RHOSQD,NISO,LOCHN,NHICHN,R,O,AT,A,RES,RHO,MVAR, NR,RAT,ST,NITER,F,RCORR,P,MAXCON,RHOSUM,XNORM,MVAR,ISO,III)

REMOVE: Defined in DELETE

BETA: Defined in DELETE

RHOSQD: $\sum (RHO(I))^2$

NISO: Defined in REFS

LOCHN: Defined in INIT

NHICHN: Defined in INIT

R(I,J): Defined in DELETE

O(J): Defined in REFS

AT(J): Defined in REFS

A(I): Defined in WATE

RES(I): Defined in PHOTO

RHO(I): Defined in WATE

NVAR: Defined in INIT

NR: Defined in INIT

RAT: Defined in INIT

ST: T -the student's t value

NITER: Number of iterations to be performed

F: F value for null hypothesis

RCORR: Correlation coefficient

P: Tag name for the reference isotope

MAXCON: Remaining number of isotopes after deletions

RHOSUM: $\sum (RHO(I))$

XNORM: Defined in REFS

MVAR: Defined in INIT

ISO: Defined in REFS

III: Defined in REFS

16. WRIT:

This program is used to print the concentration estimators, standard deviations, t values, etc.

SUBROUTINE WRIT (NITER,ITER,O,BETA,STDEV,ST,NISO,F,RCORR)

NITER: Iteration number

ITER: Maximum iterations

O(I): Tag number of the reference isotope

BETA: Concentration estimators (ppm)

STDEV: Standard deviations of BETA

ST: Calculated t value

NISO: Order of the isotope whose values are going to be printed

F: Calculated F value

RCORR: Correlation coefficients

This program is composed only of WRITE and FORMAT statements.

17. CHI:

This program is used to calculate the value of Chi-squared divided by the degrees of freedom for each analysis

SUBROUTINE CHI (CALC,RES,MXCON,P,O,LOCHN,NHICHN,BETA,AT,C,RHO,NISO,QUAL,A)

CALC: Intermediate value for QUAL
RES(I): Defined in PHOTO
MAXCON: Defined in STAT
P(J): Defined in STAT
O(J): Defined in REFS
LOCHN: Defined in INIT
NHICHN: Defined in INIT
BETA(J): Defined in DELETE
AT(I): Defined in REFS
C(I): Defined in REFIN
RHO(I): Defined in WATE
NISO: Defined in REFS
QUAL: Quality of fit number
A(I): Defined in WATE
UP: Confidence interval of Chi-squared
DF: Degrees of freedom

18. VARNCE:

This program is used to adjust the weighting matrix to account for the variance in the reference spectra and the concentration estimators

SUBROUTINE VARNCE (A,OMG,STDEV,AT,LOCHN,NHICHN,NISO,MAXCON,C,P,O,BETA,XNORM)

All of the variables are previously defined.

19. WRIT1:

This program is used to write the significant concentrations estimators and their standard deviations,onto an intermediate storage.

SUBROUTINE WRIT1 (O,BETA,STDEV,NISO)

All of the variables are previously defined.

APPENDIX G

- LISTING OF THE INPUT DATA AND INPUT OPTIONS

Listing of input data and input options.

The following cards and decks are read by CORGAM:

A.1 Card One (15A4 format): Identification card for the set of data which may contain more than one complex spectrum.

A.2 Card Two (25I3 format):
NISO = number of isotopes used in analyzing all complex spectra of the data set. Any analysis for which a specific isotope is not desired may be removed by entering a negative unity in the proper location of the irradiation and decay times correction factor card.

NCASES = number of complex spectra contained in the data set.

Six other control parameters are carefully defined in the comment cards of the program.

A.3 Card Three (25I3 format):
NCHG1 = 0; no change in NAM1. See the comment cards in CORGAM for the definition of the variables in NAM1

NCHG1 = 1; change in NAM1. Below is a list of the standard values of the variables of NAM1. Read one or more cards with the necessary input data

NCHG2 = 0; no change in NAM2. This namelist contains the irradiation and decay time correction factors

NCHG2 = 1; change in NAM2. The standard value for all of these correction factors is unity. Read one or more cards with the necessary input data

NCHG3 = 0; no change in NAM3. See the comment cards in CORGAM for the definition of the variables in NAM3.

NCHG3 = 1; change in NAM3. This is the standard value for NCHG3 because not all of the necessary input data is defined. Below is a list of the standard values for the variables of NAM3. Read one or more cards with the necessary input data

A.4. Card Four (15A4 format): Identification card of a specific complex spectrum from the group which is to be analyzed.

A.5 Deck One (5E14.8 or 6X,12F6.0,2X format): This is the complex spectrum.

Note: Card Five and Deck Two are not needed if NBKGD = 0 or NUBKG = 0

A.6. Card Five (15A4 format): Identification card for the background spectrum.

A.7 Deck Two (6X,12F6.0,2X format): This is the background spectrum.

        Note: Card Six and Deck Three are not needed unless NAREA = 1

A.8 Card Six (15A4 format): Identification card for the flux reference spectrum

A.9 Deck Three (6X,12F6.0,2X format): This is the flux reference spectrum

        Note: Card Seven and Cards Eight are not needed if NSHFT = 0

A.10 Card Seven (8F10.0 format): This card contains the gain (MeV/ch) to which the complex spectrum is to be shifted

A.11 Cards Eight (4(I3,7X,F10.0) format): These cards contain the approximate mid point and energy of each photopeak used in shifting the complex spectrum

        Note: If NVAR = 1, Deck Four is needed

A.12 Deck Four (5E14.8 format): This deck contains a variance spectrum corresponding to the complex spectrum.

The following cards and decks are read by subprogram REFS.

A disk is needed for intermediate storage.

        Note: There will be NISO decks consisting of Card One and Card two plus a deck of control parameters and a reference spectrum

B.1 Card One (A4,9I3 format): This card contains an identification tag and several control parameters for a reference spectrum. See subprogram REFS comment cards for definitions

B.2 Card Two (8F10.0 format): This card contains the half life (in minutes), the irradiation time (in minutes), flux reference isotope half life (in minutes), and the reference spectrum normalization constant. This normalization constant is read as unity if the reference spectrum is to be normalized.

        Note: Card Three is needed only if NO, the number spectra composing a set of reference decay spectra, is > unity.

B.3 Card Three (8F10.0 format): This card contains the decay time (in minutes) and counting time (in minutes) for each spectrum in the set of reference decay spectra. There is a maximum of five spectra allowed in each set of reference decay spectra; all the sets of reference decay spectra must come first in reference spectra decks; and each spectrum in a set of reference decay spectra must be in order of the decay times.

        Note: Cards Four, Five, Deck One, Card Six, Deck Two, are not needed if NO is zero or unity

B.4 Card Four (25I3 format): This card contains several control parameters for the set of decay reference spectra.

B.5 Card Five (8F10.0 format): This card contains the background counting
time (in minutes), the flux reference decay time (in minutes),
the sample weight (in grams), the weight of the flux reference
(in grams), and the flux reference counting time (in minutes).

B.6 Deck One (5E14.8;6X,12F6.0,2X; or 8F10.0 format): This deck contains the
set of decay reference spectra.

> Note: If NORF is zero, Card Six, Deck Two, Card Seven, Card Eight,
> and Card Nine are not needed. If NNBKG is yew, Card Six
> and Deck Two are not needed.

B.7 Card Six (15A4 format): Identification card for the background spectrum

B.8 Deck Two (6X,12F6.0, 2X format): This deck contains the background spectrum
> Note: There will NO decks composed of Card Seve, Card Eight,
> and Cards Nine

B.9 Card Seven (25I3 format): This card contains the number of peaks and the
pivotal peak used in shifting the reference spectrum.

B.10 Card Eight: See Card Seven of CORGAM

B.11 Card Nine: See Card Eight of CORGRAM

> Note: If NO is zero, some or all of the following cards or
> decks are needed. If NORF is unity, Card Ten and Card
> Eleven are needed.

B.12 Card Ten: See Card Four of REFS

B.13 Card Eleven (8F10.0 format): This card contains the counting time (in
minutes) and the information contained on Card Five of REFS
for each reference spectrum

B.14 Deck Three (5E14.8;6X,12F6.0,2X; or 8F10.0 format): This deck contains
the reference spectrum.

> Note: If NORF is not equal to unity, Card Twelve, Deck Four,
> Cards Fourteen, Card Fifteen and Deck Five are not needed.
> If NUBKG is zero, Card Twelve and Deck Four are not needed.

B.15 Card Twelve (15A4 format): Identification card for the background spectrum

B.16 Deck Four (6X,12F6.0,2X format): This deck contains a background spectrum

B.17 Card Thirteen: See Card Seven of CORGAM.

B.18 Card Fourteen: See Card Eight of CORGAM.

8.19 Card Fifteen (15A4 format): Identification card for the flux reference
spectrum

8.20 Deck Five (6X,12F6.0,2X format): This deck contains a flux reference spectrum

The following cards and decks are read by subprogram XFORM

Note: If NFORM = 1, the following deck is needed:

C.1 Deck One (3E24.18 format): This deck contains the $(X'W\,X)^{-1}$ matrix which has been formed previously

Note: If NFORM = 2, no other input is required
If NFORM = 3, the following two cards are needed.

C.2 Card One (25I3 format): This card contains the number of peaks needed for the area of interest (AOI) unfolding procedure and the number of channels on either side of the mid-point channel of the photopeak used in the AOI unfolding procedure.

C.3 Card Two (25I3 format): This card contains the channel numbers which correspond to each peak used in the AOI unfolding procedure.
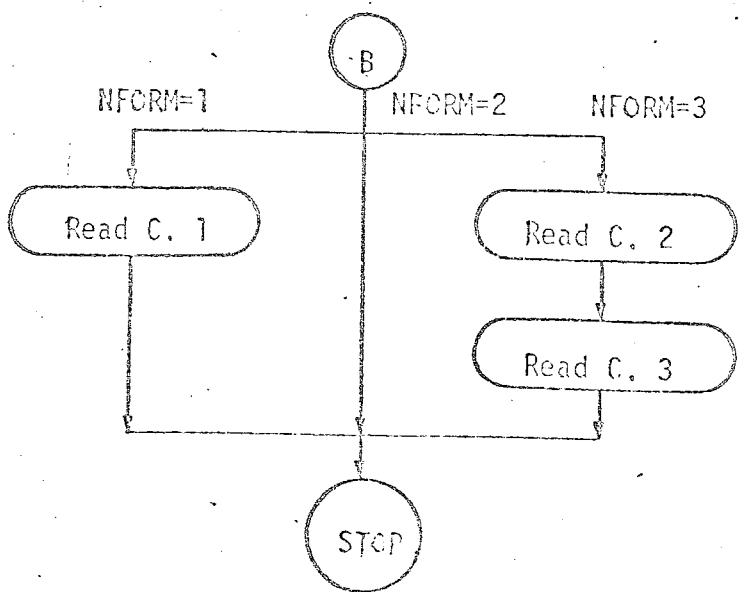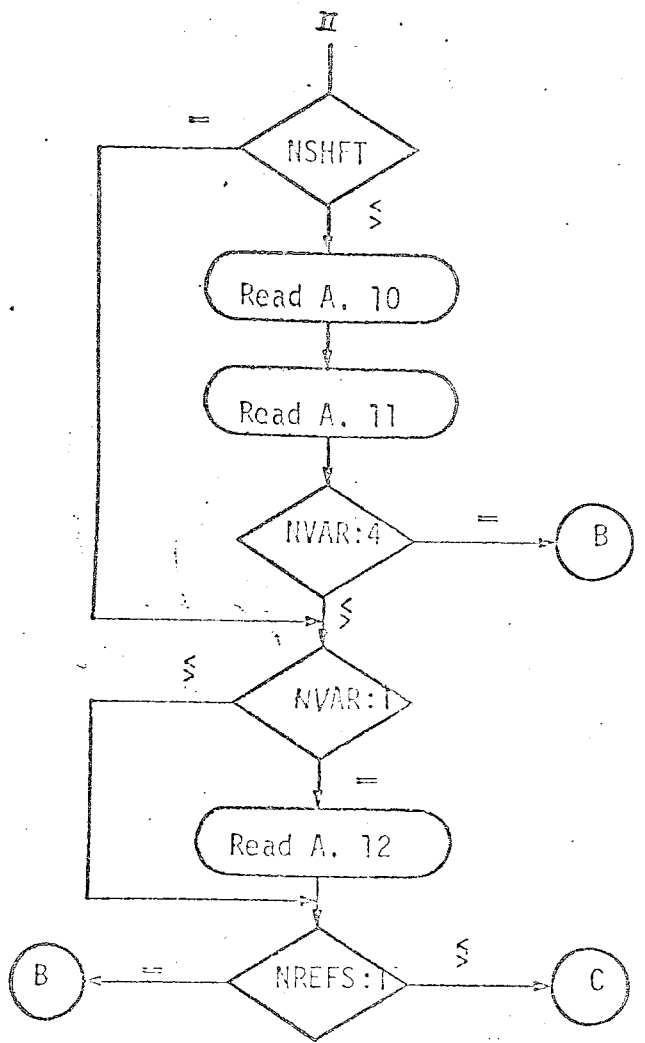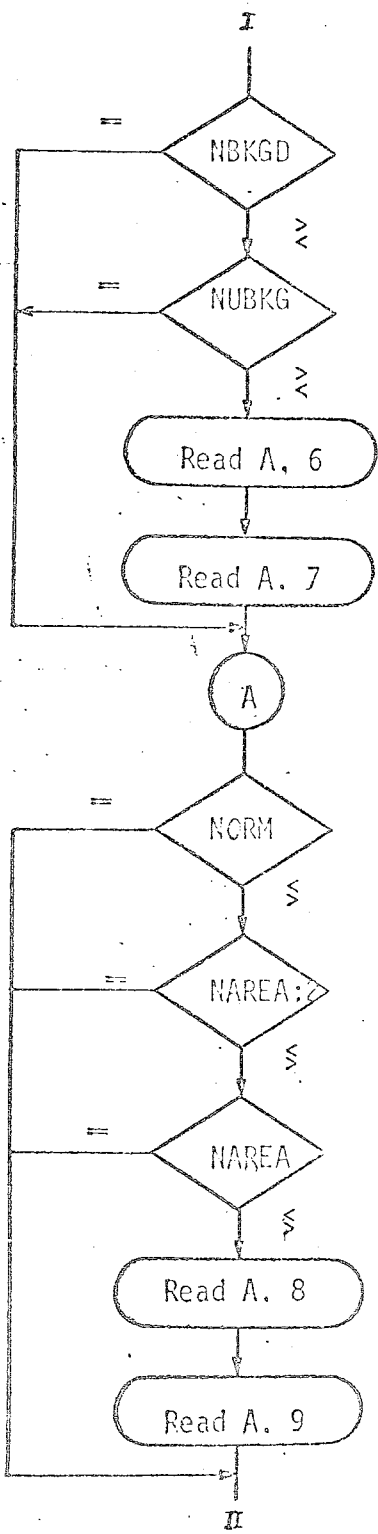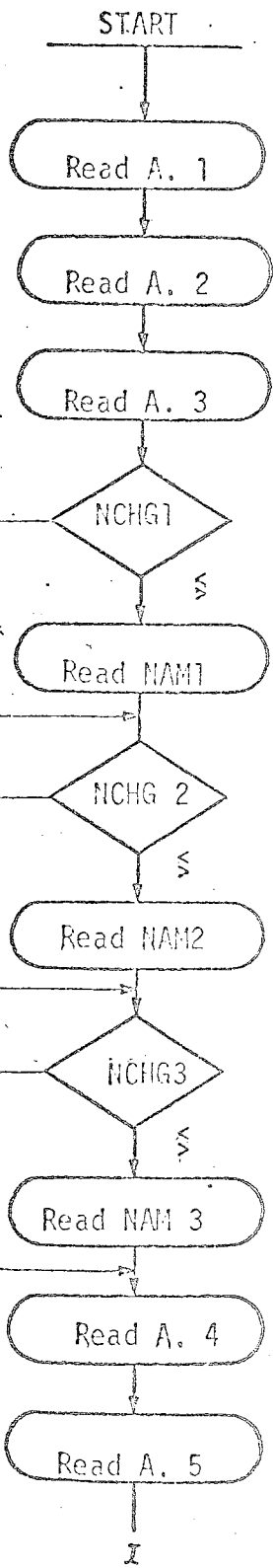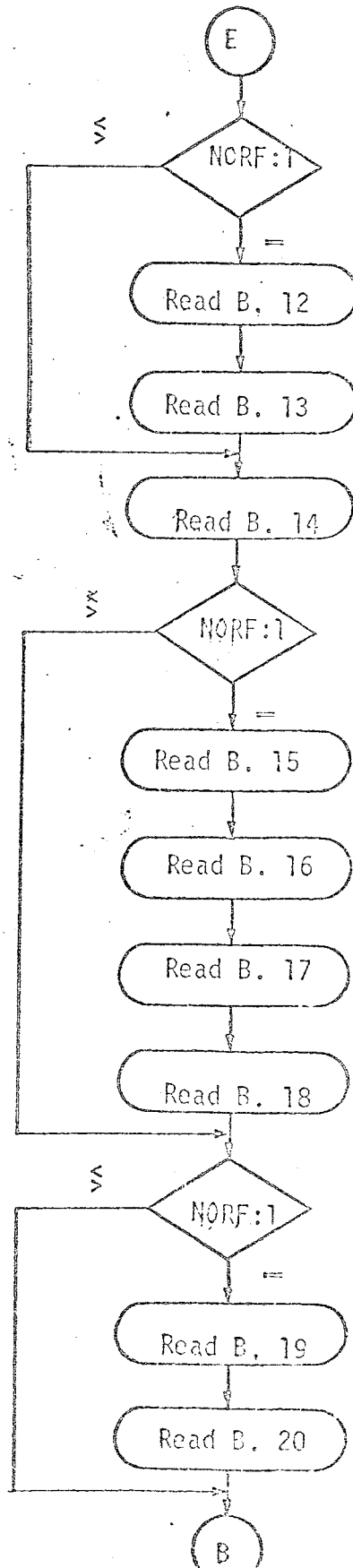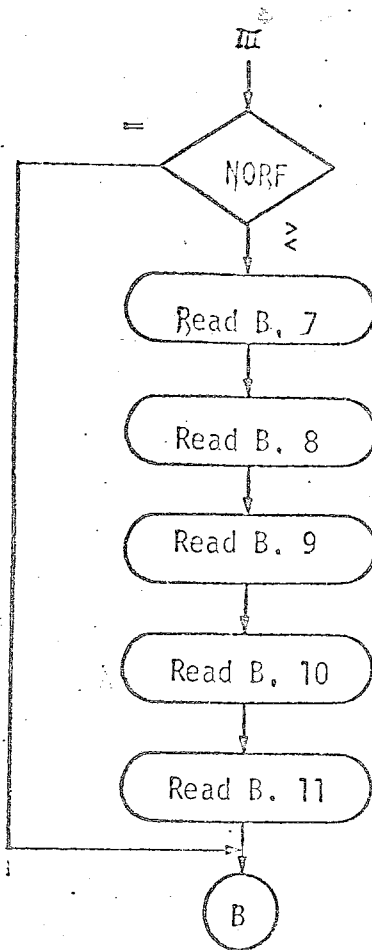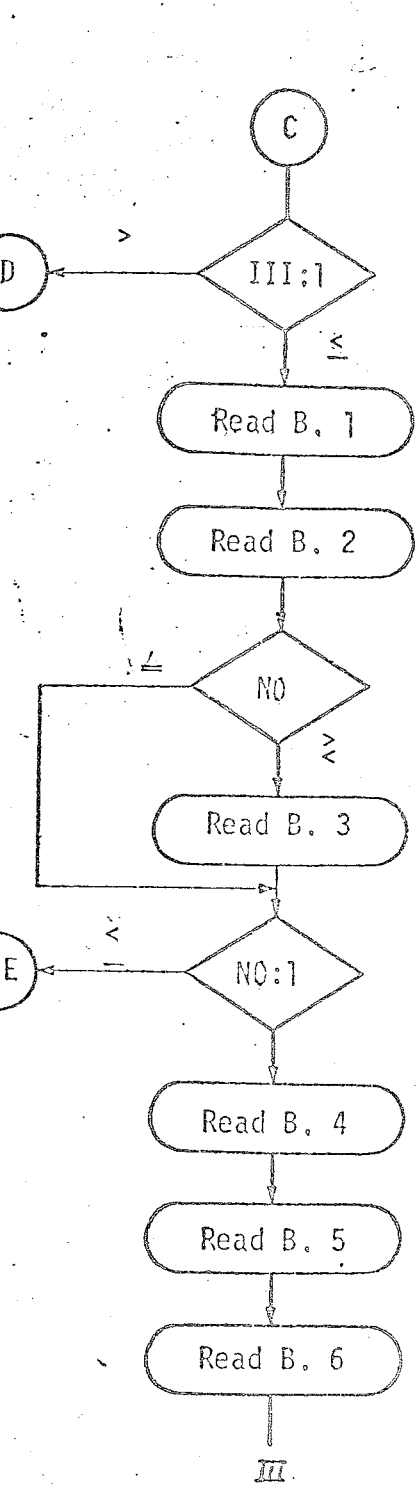
APPENDIX   H

- LISTING OF THE UNIVAC-1106 VERSION OF THE CODE (CORGAM)

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).MAIN
      DIMENSIONRHO(400),AT(400,15),A(400),THETA(15),BETA(15),P(15),R(15,CORG  1
     115),C(15),O(15),RES(400),CALC(400),RI(15,15),H(15),BKG(400),Q(15,1CORG  2
     115),D(15),ISO(15),S(15,15),S1(400),OMG(400),STDEV(400),ST(15),NFAC(CORG  3
     115),XNORM(15),OI(15),RII(15,15)                                     CORG  4
      NAMELIST /NAM1/ISOCHN,MODE,NBKGD,NUBKG,NSHFT,NPK,LPP,NORM,NCTIN,    CORG
     1NAREA,NCHCU,NCULL,NCUUL,NRHO,NUMVAR,NVAR,NREFS,ITER,NR,NW,LOCHN,     CORG
     2NHICHN,NCHAN,MC,MVAR/NAM2/C/NAM3/T,DECAY,COUNT,WT,CUCT,WTCU,AREA,    CORG
     3CUDEC,BKGTIM,TIMIRR,FRHL,UP,XNCOM                                    CORG
      DATA NITER, RAT, SAV, C/0,1.0,0.0,15*1.0/                           CORG  5
      DATA ISOCHN, MODE, NBKGD, NUBKG, NSHFT, NPK, LPP, NORM, NCTIN,      CORG  6
     1NAREA, NCHCU, NCULL, NCUUL, NRHO, NUMVAR, NVAR, NREFS, ITER, NR,    CORG  7
     2NW, LOCHN, NHICHN, NCHAN, MC, MVAR/256,2,1,1,1,3,1,1,1,1,48,33,40,1CORG  8
     3,1,3,0,0,0,1,7,250,256,1,0/                                         CORG  9
      DATA T, AREA, BKGTIM, TIMIRR, FRHL, UP, XNCOM/1.645,1.0,60.0,15.0,  CORG 10
     11774.0,2.5758,1.0/                                                  CORG 11
    9 FORMAT( 1H1 )                                                       CORG 12
   10 FORMAT( 25I3 )                                                      CORG 13
   11 FORMAT( 5E14.8 )                                                    CORG 14
   12 FORMAT(8F10.0)                                                      CORG 15
   13 FORMAT( /24HL (ATRANS * OMEGA * RHO)/)                              CORG 16
   14 FORMAT( 11H T VALUE = ,F7.4)                                        CORG 17
   15 FORMAT( 15A4 )                                                      CORG 18
   16 FORMAT(/35HL DECAY AND IRR CORRECTION FACTORS  /)                   CORG 19
   17 FORMAT(/23HL SOLUTION VECTOR (PPM) /)                               CORG 20
   18 FORMAT( I4,(1X, 10E12.5) )                                          CORG 21
   20 FORMAT( 2(1X,I3,1X,E12.5,1X,E12.5,1X,E12.5) )                       CORG 22
   21 FORMAT( 1H1,2(1X,3HCHN,5X,3HEXP,10X,4HCALC,10X,3HRES,4X) )          CORG 23
   22 FORMAT( 1X,A4,(1X,9E12.5))                                          CORG 24
   24 FORMAT( A4,9I3 )                                                    CORG 25
   27 FORMAT( I4,6(2X,A4,3H = ,E12.5) )                                   CORG 26
   29 FORMAT( 3E24.18 )                                                   CORG 27
   34 FORMAT( 6X,12F6.0,2X )                                              CORG 28
   35 FORMAT( 35H NO VARIABLES SIGNIFICANT AT A T = ,F5.1 )               CORG 29
   36 FORMAT(/15H CU REF AREA = ,E14.8/)                                  CORG 30
   38 FORMAT(/ 18H ABS DEV PER PT = ,E14.7,13H NO OF PTS = ,I3 /)         CORG 31
   39 FORMAT(/6X,9(4X,A4,4X))                                             CORG 32
   40 FORMAT(17H SAMPLE WT(GM) = ,E12.5,17H IRR TIME(MIN) = ,E12.5,19H DCORG 33
     1ECAY TIME(MIN) = ,E12.5,14H COUNT TIME = ,E12.5/19H FLUX REF WT(GMCORG 34
     2) = ,F12.5,23H REF DECAY TIME(MIN) = ,E12.5,23H REF COUNT TIME(MINCORG 35
     3) = ,F12.5,18H REF HLIFE(MIN) = ,E11.4/17H BKG TIME(MIN) = ,E12.5)CORG 36
   50 FORMAT(/19H Y NORM CONSTANT = ,E15.8/)                              CORG 37
   51 FORMAT(8F10.3)                                                      CORG 38
  198 READ(5,15)(P(I),I=1,15)                                             CORG 39
      READ(5,10)NISO,NCASES,NRES,NFORM,NWRIT,NCORR,NINTF,NIDEN            CORG 40
      NRES=0 NO RES CALC                                                  CORG 41
         =1 RES CALC BUT NOT WRITTEN OUT,JUST UND OUTSIDE ABS(2)          CORG 42
         =2 RES CALC AND WRITTEN OUT                                      CORG 43
      NFORM = 1 READ INV COR MATRIX                                       CORG 44
            = 2 FORM INV COR MATRIX                                       CORG 45
            = 3 TAKE ONLY PEAK CHAN VALUES FOR LST SQRS FIT               CORG 46
      NWRIT = 0 WRITE R AND RINV MATRICES                                 CORG 47
            OTHER DO NOT WRITE R AND RINV MATRICES                        CORG 48
      NCORR = 0 FORM CORRELATION COEFF                                    CORG 49
            OTHER DO NOT FORM CORRELATION COEFF                           CORG 50
      NINTF = 0 INTERFERENCES WILL BE CALCULATED                         CORG 51
            OTHER INTERFERENCES WILL NOT BE CALCULATED                    CORG 52
      NIDEN = 0 CALC THE IDENTITY MATRIX FROM THE INVERSE                 CORG 53
            OTHER DO NOT CALC THE IDENT                                   CORG 54
      IF(NISO.EQ.0)CALL EXIT                                             CORG 55
      NHI=NHICHN                                                          CORG 56
      WRITE(6,9)                                                          CORG 57
      WRITE(6,15)(P(I),I=1,15)                                            CORG 58
      ISOCHN = NO OF CHN IN COMPLEX SPECTRUM                              CORG 59
      MODE = 1 READ BY 5E14.8                                             CORG 60
           = 2 READ BY 6X,12F6.0,2X                                       CORG 61
      MAXCON=NISO                                                         CORG 62
      NBKGD = 0 NO BKGD SUBTRACTION                                       CORG 63
            OTHER WILL SUBTRACT BKGD                                      CORG 64
      NUBKG = 0 NO NEW BKGD TO BE READ                                    CORG 65
            OTHER A NEW BKGD WILL BE READ                                 CORG 66
      NSHFT = 0 NO SPECTRUM SHIFTING                                      CORG 67
            OTHER WILL SHIFT SPECTRUM                                     CORG 68
      NPK = NO OF PEAKS IN SPECT FOR SHIFTING                             CORG 69
      LPK = INDEX OF PK USED IN SHIFT RATIO                               CORG 70
      NORM = 0 NO NORMALIZATION OF COMPLEX NEEDED                         CORG 71
           = OTHER NORMALIZE THE COMPLEX                                  CORG 72
      NCTIN = 0 READ PRECALC CORRECTION FACTORS                          CORG 73
            = OTHER READ UNITY (OR LT ZERO FOR DELETION)                  CORG 74
      NAREA = 0 READ 5P AREA FOR CU REF                                   CORG 75
            = UNITY CALC PP AREA FOR CU REF,READ CU SPECT(READ ANY)       CORG 76
            = 2 USE SAME AREA AS PREVIOUS SPECTRUM                        CORG 77
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          NCHCU = NO OF CHAN IN CU REF SPECT                                  CORG  78
          NCHLL = LOWER FIT LIMIT ON CU REF PP                                 CORG  79
          NCUUL = UPPER FIT LIMIT ON CU REF PP                                 CORG  80
          NRHO = 0 WILL NOT PUNCH SHIFTED OUTPUT                               CORG  81
               = OTHER WILL PUNCH SHIFTED OUTPUT                               CORG  82
          NUMVAR = NO OF VAR TO AVERAGED                                       CORG  83
          NVAR   = 1 READ VAR     BY 5E14.8                                    CORG  84
                 = 2 VAR = 1.0                                                 CORG  85
                 = 3 VAR = RHO                                                 CORG  86
                 = 4 USE VAR PREVIOUSLY READ                                   CORG  87
          NREFS = 0 NEW SET OF REF SPECT ARE READ                             CORG  88
                = 1 NO NEW REF SPECT ARE TO BE READ                           CORG  89
          ITER = NO OF ITERATIONS ON VARIANCE                                 CORG  90
          ITER MUST = 0 IF NVAR = 1,2,4                                       CORG  91
          NR = 0 CALC AVE WT VAR THE LONG WAY                                 CORG  92
               = OTHER RATIO = YAVE/YAVEAVE                                    CORG  97
          NW = 0 WILL NOT PUNCH SHIFTED OTPT FOR REF SPECT                    CORG  98
               = OTHER WILL PUNCH SHIFTED OTPT FOR REF SPECT                  CORG  99
          LOCHN = LOWER CHN OF LST SQRS FIT                                   CORG 100
          NHICHN = UPPER CHN OF LST SQRS FIT                                  CORG 101
          NCHAN = NO OF CHN IN VAR SPECT IF VAR ARE TO BE READ                CORG 102
          MC = NO OF REF SPECT WHICH HAVE A SET OF DECAY SPECTRA.  THESE  CORG 103
               SPECTRA MUST BE IN ORDER AND THEY MUST BE THE FIRST OF THE CORG 104
               REF SPECTRA TO BE READ IN                                      CORG 105
          MVAR = 0 VAR OF REF SPECT = REF SPECT                              CORG 106
               = OTHER READ VAR OF REF SPECT                                  CORG 107
          C(I) = REAL CORRECTION FACTORS (NCTIN = 0)                          CORG 108
               = ZERO  OR LESS,USED FOR DELETION,NCTIN GT 0)                  CORG 109
          T = STUDENTS T VALUE FOR NULL HYPOTHESIS TEST                       CORG 110
          BLSHFT =BASE LINE SHIFT ( NEG SHIFTS ZERO LEFT )                    CORG 111
          E = PP ENERGY (USED IN SHIFTING)                                    CORG 112
          DECAY = DECAY TIME (MIN) FOR COMPLEX                                CORG 113
          COUNT = COUNT TIME(MIN) FOR COMPLEX                                 CORG 114
          AREA = CU -EF PP NORMALIZED AREA                                    CORG 115
          WT = COMPLEX WT(GM)                                                 CORG 116
          WTCU = WT OF CU REF (GM)                                            CORG 117
          CUCT = CU REF COUNT TIME(MIN)                                       CORG 118
          IF NAREA = 0,WTCU AND CUCT MUST EQUAL TO 1.0                        CORG 119
          CUDEC = DECAY TIME OF CU REF(MIN)                                   CORG 120
          BKGTIM = COUNT TIME OF BKGD(MIN)                                    CORG 121
          TIMIRR = COMPLEX SAMPLE IRR TIME                                    CORG 122
          FRHL = FLUX REF HALF LIFE (MIN)                                     CORG 123
          UP = U-SUB-P FACTOR CHISQR TEST                                     CORG 124
          XNCOM = COMPLEX SPECTRUM NORM CONST                                 CORG 125
       DO 1002 III=1,NCASES                                                   CORG 126
       IF(III.LE.1)GO TO 3011                                                 CORG 127
       CALL INIT(NITER,RAT,SAV,C,ISOCHN,MODE,NBKGD,NUBKG,NSHFT,NPK,LPP,NOCORG 128
      1RM,NCTIN,NAREA,NCHCU,NCULL,NCUUL,NRHO,NUMVAR,NVAR,NREFS,ITER,NR,NWCORG 129
      2,LOCHN,NHICHN,NCHAN,MC,MVAR,T,AREA,BKGTIM,TIMIRR,FRHL,JP,XNCOM)        CORG 130
   11  READ(5,10)NCHG1,NCHG2,NCHG3                                            CORG 131
       IF(NCHG1.EQ.0)GO TO 52                                                 CORG 132
       READ(5,NAM1)                                                           CORG 133
   52  IF(NCHG2.EQ.0)GO TO 53                                                 CORG 134
       READ(5,NAM2)                                                           CORG 135
   53  IF(NCHG3.EQ.0)GO TO 54                                                 CORG 136
       READ(5,NAM3)                                                           CORG 137
   54  READ(5,15)(P(I),I=1,15)                                                CORG 138
       PO=P(1)                                                                CORG 139
       GO TO (111,134),MODE                                                   CORG 140
   11  READ(5,11)(RHO(I),I=1,ISOCHN)                                          CORG 141
       GO TO 135                                                              CORG 142
   34  READ(5,34)(RHO(I),I=1,ISOCHN)                                          CORG 143
   35  WRITE(6,15)(P(I),I=1,15)                                               CORG 144
       WRITE(6,46)WT,TIMIRR,DECAY,COUNT,WTCU,CUDEC,CUCT,FRHL,BKGTIM           CORG 145
       IF(NRHO.EQ.0)GO TO 3333                                                CORG 146
       WRITE(2,15)(P(I),I=1,15)                                               CORG 147
   33  IF(NBKGD.EQ.0) GO TO 3170                                              CORG 148
       FACT=COUNT/BKGTIM                                                      CORG 149
       IF(NUBKG.EQ.0)GO TO 374                                                CORG 150
       READ(5,15)(P(I),I=1,15)                                                CORG 151
       READ(5,34)(BKG(I),I=1,ISOCHN)                                          CORG 152
   74  DO 318 I=1,ISOCHN                                                      CORG 153
       RHO(I)=RHO(I)-BKG(I)*FACT                                              CORG 154
       IF(RHO(I).LT.0.)RHO(I)=0.0                                             CORG 155
   18  CONTINUE                                                               CORG 156
   70  SF=1.0                                                                 CORG 157
       IF(TIMIRR.EQ.15.)GO TO 317                                            CORG 158
       SF=(1.-EXP(-ALOG(2.)*TIMIRR/FRHL))/(1.-EXP(-ALOG(2.)*15./FRHL))       CORG 159
   17  IF(NORM.EQ.0)GO TO 133                                                 CORG 160
       IF(NAREA.EQ.2)GO TO 3171                                              CORG 161
       IF(NAREA.EQ.0)GO TO 370                                               CORG 162
       READ(5,15)(P(I),I=1,15)                                               CORG 163
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      READ(5,34)(RES(I),I=1,NCHCU)                                       CORG 164
      CALL PHOTO(RES,XO,NCULL,NCUUL,0,511,AREA )                          CORG 165
      CUDEC=CUDEC+CUCT/2.                                                 CORG 166
      AREA=AREA*EXP(CUDEC*ALOG(2.)/FRHL)/(WTCU*CUCT)                      CORG 167
  570 WRITE(6,36)AREA                                                     CORG 168
  171 XNCOM=AREA*WT*1.0E-06*COUNT*SF                                      CORG 169
      DO 131 I=1,ISOCHN                                                   CORG 170
  131 RHO(I)=RHO(I)/XNCOM                                                 CORG 171
      WRITE(6,50)XNCOM                                                    CORG 172
  133 IF(NSHFT.EQ.0) GO TO 3013                                           CORG 173
      ICHN=ISOCHN                                                         CORG 174
      CALL SHIFT(ISOCHN,NPK,LPP,NRHO,RHO,PO)                              CORG 175
      RATIO=(FLOAT(ISOCHN)-0.5)/FLOAT(ICHN)                               CORG 176
      NHICHN=FLOAT(NHICHN)*RATIO+0.5                                      CORG 177
      LOCHN=FLOAT(LOCHN)*RATIO+0.5                                        CORG 178
      IF(NVAR.EQ.4) GO TO 3190                                            CORG 179
 3013 CALL WATE(NVAR,NUMVAR,NCHAN,RHO,XNCOM,III,OMG,A,RES,ISOCHN)         CORG 180
      IF(DECAY.EQ.SAV ) GO TO 3190                                        CORG 181
      IF(III.GT.1)GO TO 3195                                              CORG 182
      SAV =DECAY                                                          CORG 183
 3195 IF(NREFS.EQ.1)GO TO 3190                                            CORG 184
      CALL REFS(NISO,NHICHN,ISO,XNORM,0,AT,RKG,NW,DECAY,COUNT,III,NFAC,   CORG 185
     1FRRHL,D,H,MC,NO)                                                    CORG 185
 3190 DO 978 I=1,MAXCON                                                   CORG 186
      IF(NCTIN.EQ.0)GO TO 978                                            CORG 187
      XN=(1.-EXP(-ALOG(2.)*15./FRRHL))                                    CORG 188
      SF=XN/(1.-EXP(-ALOG(2.)*D(I)/FRRHL))                                CORG 189
      XL=ALOG(2.)/H(I)                                                    CORG 190
      IF(NFAC(I).EQ.0)GO TO 3337                                          CORG 191
      FACT=1.0                                                            CORG 192
      GO TO 130                                                           CORG 193
 3337 TB=DECAY-ALOG((1.-EXP(-XL*COUNT))/(COUNT*XL))/XL                    CORG 194
      FACT=EXP(XL*TB)                                                     CORG 195
  130 C(I)=FACT*C(I)*1.0E+06*SF*(1.-EXP(-XL*D(I)))/(1.-EXP(-XL*15.))      CORG 196
  978 P(I)=O(I)                                                           CORG 197
      WRITE(6,16)                                                         CORG 198
      WRITE(6,27)NISO,(O(I),C(I),I=1,NISO)                                CORG 199
      IF(NVAR.EQ.4)GO TO 319                                              CORG 200
   99 CALL XFORM(NFORM,NISO,R,RI,MAXCON,P,O,LOCHN,NHICHN,A,AT,NCORR,NWRI  CORG 201
     1I,NIDEN,NINTF,RII,BETA,THETA,OI,RHO,III)                           CORG 202
  319 RHOSUM=0.                                                          CORG 203
  132 RHOSQD=0.                                                          CORG 204
      REMOVE=0.                                                          CORG 205
      DO 120 I=LOCHN,NHICHN                                               CORG 206
      IF(A(I).EQ.0.0)A(I)=1.0                                            CORG 207
      RHOSQD=RHOSQD+(RHO(I)**2)/A(I)                                     CORG 208
  120 RHOSUM=RHOSUM+RHO(I)/A(I)                                          CORG 209
  266 RAT=RHOSUM/FLOAT(NHICHN-LOCHN+1)                                   CORG 210
C        FORM ATRANS * OMEGA * RHO                                        CORG 211
  253 DO 117 K=1,NISO                                                     CORG 212
  117 THETA(K)=0.0                                                        CORG 213
      L=1                                                                 CORG 214
      DO 4050 K=1,MAXCON                                                  CORG 215
      IF(P(K).NE.O(L))GO TO 4050                                          CORG 216
      DO 1000 I=LOCHN,NHICHN                                              CORG 217
 1000 THETA(L)=THETA(L)+AT(I,K)*RHO(I)/A(I)                               CORG 218
      L=L+1                                                               CORG 219
      IF(L.GT.NISO)GO TO 4051                                            CORG 220
 4050 CONTINUE                                                           CORG 221
 4051 WRITE(6,13)                                                         CORG 222
      WRITE(6,18)NISO,(THETA(I),I=1,NISO)                                 CORG 223
      WRITE(6,9)                                                          CORG 224
  701 DO 106 J=1,NISO                                                     CORG 225
      BETA(J)=0.0                                                        CORG 226
      DO 106 I=1,NISO                                                     CORG 227
  106 BETA(J)=BETA(J)+R(J,I)*THETA(I)                                     CORG 228
      DO 125 I=1,NISO                                                     CORG 229
  125 BETA(I)=BETA(I)*C(I)                                                CORG 230
      DO 500 I=1,NISO                                                     CORG 231
  500 REMOVE=REMOVE+BETA(I)*THETA(I)/C(I)                                 CORG 232
      ISOCHN=NISO                                                         CORG 233
      L=1                                                                 CORG 234
  602 IF(C(L))601,600,600                                                 CORG 235
  601 CALL DELETE(NISO,REMOVE,ISOCHN,BETA,R,C,O,THETA,L)                  CORG 236
      L=L-1                                                               CORG 237
  600 L=L+1                                                               CORG 238
      IF(L.LE.NISO)GO TO 602                                             CORG 239
      CALL STAT(REMOVE,BETA,RHOSQD,NISO,LOCHN,NHICHN,R,C,O,AT,A,STDEV,RH  CORG 240
     1O,NVAR,NR,RAT,ST,NITER,F,RCORR,P,MAXCON,RHOSUM,XNORM,MVAR,ISO,III)  CORG 241
      CALL WRIT(NITER,ITER,O,BETA,STDEV,ST,NISO,F,RCORR)                  CORG 242
  252 IF(ITER.EQ.0)GO TO 262                                             CORG 243
      IF(NITER.GE.ITER)GO TO 262                                         CORG 244
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        CALL CHI(CALC,RES,MAXCON,P,O,LOCHN,NHICHN,BETA,AT,C,RHO,NISO,CHIS,CORG   246
     1A)                                                                    CORG   247
        NITER=NITER+1                                                       CORG   248
        NCTIN=0                                                             CORG   249
        JPMX=HP*SQRT(2./FLOAT(NHICHN-LOCHN-NISO))+1.                        CORG   250
        IF( CHIS .LE. JPMX)GO TO 262                                        CORG   251
        CALL VARNCE(A,OMG,STDEV,AT,LOCHN,NHICHN,NISO,MAXCON,C,P,O,BETA,XNOCORG   252
     1RM)                                                                   CORG   253
        NFORM=2                                                             CORG   254
        GO TO 99                                                           CORG   255
    262 ISOCHN=NISO                                                         CORG   256
        NITER=0                                                            CORG   257
        AMIN=ST(1)                                                         CORG   258
        DO 950 I=1,NISO                                                    CORG   259
        IF(AMIN.LT.ST(I)   )GO TO 950                                      CORG   260
        L=I                                                               CORG   261
        AMIN=ST(I)                                                        CORG   262
    950 CONTINUE                                                           CORG   263
        IF(AMIN.GT.T)GO TO 951                                            CORG   264
        IF(NISO.GT.1)GO TO 953                                            CORG   265
        WRITE(6,35)T                                                      CORG   266
        GO TO 954                                                         CORG   267
    953 CALL DELETE(NISO,REMOVE,ISOCHN,BETA,R,C,O,THETA,L)                 CORG   268
        CALL STAT(REMOVE,BETA,RHOSQD,NISO,LOCHN,NHICHN,R,C,O,AT,A,STDEV,RHCORG   269
     10,NVAR,NR,RAT,ST,NITER,F,RCORR,P,MAXCON,RHOSUM,XNORM,MVAR,ISO,III)CORG   270
        CALL WRIT(NITER,ITER,O,BETA,STDEV,ST,NISO,F,RCORR)                 CORG   271
        IF(NISO.GT.0)GO TO 951                                            CORG   272
        WRITE(6,35)T                                                      CORG   273
        NISO=MAXCON                                                       CORG   274
        CALL SAVE(NISO,OI,O,RII,R)                                        CORG   275
        GO TO 1002                                                        CORG   276
    951 IF(NISO.LT.ISOCHN)GO TO 952                                       CORG   277
    954 DEG=NHICHN-LOCHN-NISO                                             CORG   278
        IF(NRFS.EQ.0)GO TO 959                                            CORG   279
        CALL CHI(CALC,RES,MAXCON,P,O,LOCHN,NHICHN,BETA,AT,C,RHO,NISO,CHIS,CORG   280
     1A)                                                                   CORG   281
        REMOVE=0.                                                         CORG   282
        DO 871 J=LOCHN,NHICHN                                             CORG   283
    871 REMOVE=REMOVE+RES(J)**2                                           CORG   284
        REMOVE=SQRT(REMOVE)                                              CORG   285
        NOP=NHICHN-LOCHN+1                                               CORG   286
        TOTAL=0.0                                                        CORG   287
        DO 980 J=LOCHN,NHICHN                                            CORG   288
    980 TOTAL=TOTAL+ABS(RES(J))                                          CORG   289
        TOTAL=TOTAL/FLOAT(NOP)                                          CORG   290
        WRITE(6,38)TOTAL,NOP                                            CORG   291
        IF(NRFS.NE.2)GO TO 959                                          CORG   292
        WRITE(6,21)                                                     CORG   293
        WRITE(6,20)(J,RHO(J),CALC(J),RES(J),J=LOCHN,NHICHN)             CORG   294
    959 CALL WRIT1(O,BETA,STDEV,NISO)                                   CORG   295
        NISO=MAXCON                                                    CORG   296
        WRITE(6,14)T                                                    CORG   297
        WRITE(6,9)                                                     CORG   298
        CALL SAVE(NISO,OI,O,RII,R)                                     CORG   299
        NHICHN=NHI                                                     CORG   300
   1002 CONTINUE                                                        CORG   301
        GO TO 198                                                      CORG   302
        END                                                           CORG   303
        SUBROUTINE REFS(NISO,NHICHN,ISO,XNORM,O,AT,BKG,NW,DECAY,COUNT,III,REFS     1
     1NFAC,FRRHL,D,H,MC,NO,RHO,A)                                       REFS     2
        DIMENSION ISO(15),H(15),D(15),XNORM(15),O(15),AT(400,15),BKG(400),REFS     3
     1RES(400),P(15),CALC(400),NFAC(15),CT(400,5),T(5),C(5),RHO(400),A(4REFS     4
     1200)                                                              REFS     5
     10 FORMAT( 25I3 )                                                  REFS     6
     11 FORMAT( 5E14.8 )                                                REFS     7
     12 FORMAT(8F10.0 )                                                 REFS     8
     15 FORMAT( 15A4 )                                                  REFS     9
     18 FORMAT( I4,(1X,  10E12.5 ) )                                    REFS    10
     24 FORMAT( A4,9I3 )                                                REFS    11
     34 FORMAT( 6X,12F5.0,2X )                                          REFS    12
     36 FORMAT(/15H CU REF AREA = ,E14.8/)                              REFS    13
     39 FORMAT(/6X,9(4X,A4,4X))                                         REFS    14
     51 FORMAT(8F10.3)                                                  REFS    15
        REWIND 10                                                      REFS    16
        MM = 1                                                         REFS    17
        DO 121 I=1,NISO                                                REFS    18
        IF(III.GT.1)GO TO 3194                                         REFS    19
        READ(5,24)O(I),ISO(I),NPK,LPP,NORF,MODE,NFAC(I),NO             REFS    20
        READ(5,12)H(I),D(I),FRRHL,XNORM(I)                            REFS    21
        IF(NO.EQ.0)GO TO 91                                            REFS    22
        READ(5,12)(T(J),C(J),J=1,NO)                                  REFS    23
        ISOCHN = NO OF CHN IN REF                                     REFS    24
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             O.PE= TAG NAME OF REF SPECT                                        REFS    25
             NPK = NO OF PKS IN REF SPECT FOR SHIFTING                          REFS    26
             LPP = INDEX OF PIVOTAL PK FOR SHIFTING                             REFS    27
             NORF = 1 NORM OF REF REQD                                          REFS    28
             MODE = 1 5E14.8  INPUT FORMAT                                      REFS    29
                  = 2 6X,12F6.0,2X  INPUT FORMAT                                REFS    30
                  = 3 8F10.0  INPUT FORMAT                                      REFS    31
             NFAC = 0 REF IS AT TIME ZERO                                       REFS    32
             NFAC = 1 REF NEEDS DECAY CORRECTION                                REFS    33
                  = GT 1 REF IS AT TIME OF COMPLEX                              REFS    34
             NO = NO OF SPECT IN THE SET OF REF DECAY SPECT                     REFS    35
             H = HALF LIFE OF REF SPECT                                         REFS    36
             D = IRRAD TIME OF REF SPECT ( MIN )                                REFS    37
             FRFHL = FLUX REF HALF LIFE FOR REF (MIN)                           REFS    38
             T = DECAY TIME (MIN) OF REF SPECT                                  REFS    39
             C = COUNT TIME (MIN) OF REF SPECT                                  REFS    40
   91     PO=O(I)                                                               REFS    41
          ISOCHN=ISO(I)                                                         REFS    42
          DO 1114 J=1,400                                                       REFS    43
 1114     AT(J,I)=0.0                                                           REFS    44
          IF(NO.LE.1)GO TO 256                                                  REFS    45
          READ(5,10)NUBKG,NCJLL,NCUUL,NCHCU,NCHRK                              REFS    46
          READ(5,12)COUN ,DECA ,BKGTIM,CUDEC,WT,WTCU,CUCT                       REFS    47
          DO114 M=1,NO                                                          REFS    48
          DO115 J=1,ISOCHN                                                      REFS    49
 115      CT(J,M)=0.0                                                           REFS    50
          GO TO(116,117,118),MODE                                              REFS    51
 116      READ(5,11)(CT(J,M),J=1,ISOCHN)                                        REFS    52
          GO TO 114                                                            REFS    53
 117      READ(5,34)(CT(J,M),J=1,ISOCHN)                                        REFS    54
          GO TO 114                                                            REFS    55
 118      READ(5,12)(CT(J,M),J=1,ISOCHN)                                        REFS    56
 114      CONTINUE                                                             REFS    57
          FACT=0.0                                                             REFS    58
          IF(NORF.EQ.0)GO TO 257                                               REFS    59
          IF(NUBKG.EQ.0)GO TO 262                                              REFS    60
          READ(5,15)(P(J),J=1,15)                                              REFS    61
          READ(5,34)(BKG(J),J=1,NCHBK)                                         REFS    62
 262      DO 259 K=1,NO                                                        REFS    63
          FACT=C(K)/BKGTIM                                                     REFS    64
          READ(5,10)NPK,LPP                                                    REFS    65
          DO 258 J=1,ISOCHN                                                    REFS    66
          CALC(J)=CT(J,K)-FACT*BKG(J)                                          REFS    67
 258      IF(CALC(J).LT.0.)CALC(J)=0.0                                         REFS    68
 265      ICHN=ISOCHN                                                          REFS    69
          CALL SHIFT(ICHN,NPK,LPP,0,CALC,PO)                                   REFS    70
          IF(ICHN.GT.NHICHN)ICHN=NHICHN                                        REFS    71
          DO 259 J=1,ICHN                                                      REFS    72
 259      CT(J,K)=CALC(J)                                                      REFS    73
          ISOCHN=ICHN                                                          REFS    74
          ISO(I)=ISOCHN                                                        REFS    75
          GO TO 257                                                            REFS    76
 256      IF(NORF.NE.1)GO TO 93                                                REFS    77
          READ(5,10)NJBKG,NCJLL,NCUUL,NCHCU,NCHRK                             REFS    78
          READ(5,12)COUN ,DECA ,BKGTIM,CUDEC,WT,WTCU,CUCT                       REFS    79
 93       GO TO (21,22,23),MODE                                               REFS    80
 21       READ(5,11)(AT(J,I),J=1,ISOCHN)                                        REFS    81
          GO TO 224                                                            REFS    82
 22       READ(5,34)(AT(J,I),J=1,ISOCHN)                                        REFS    83
          GO TO 224                                                            REFS    84
 23       READ(5,12)(AT(J,I),J=1,ISOCHN)                                        REFS    85
 224      IF(NORF.NE.1)GO TO 910                                               REFS    86
          FACT=0.0                                                            REFS    87
          FACT=COUN/BKGTIM                                                    REFS    88
          IF(NUBKG.EQ.0)GO TO 264                                             REFS    89
          READ(5,15)(P(J),J=1,15)                                             REFS    90
          READ(5,34)(BKG(J),J=1,NCHBK)                                        REFS    91
          GO TO 264                                                           REFS    92
 264      DO 260 J=1,ISOCHN                                                   REFS    93
          CALC(J)=AT(J,I)-FACT*BKG(J)                                         REFS    94
 260      IF(CALC(J).LT.0.)CALC(J)=0.0                                        REFS    95
          CALL SHIFT(ISOCHN,NPK,LPP,0,CALC,PO)                                REFS    96
          IF(ISOCHN.GT.NHICHN)ISOCHN=NHICHN                                   REFS    97
          DO 261 J=1,ISOCHN                                                   REFS    98
 261      AT(J,I)=CALC(J)                                                     REFS    99
 257      ISO(I)=ISOCHN                                                       REFS   100
          IF(NO.LE.1)GO TO 910                                                REFS   101
 94       CALL REFIN(AT,III,T,C,CT,NO,I,DECAY,COUNT,ISO,RHO,A)                 REFS   102
          WRITE(6,39)O(I)                                                     REFS   103
          IC=ISO(I)                                                           REFS   104
          WRITE(6,18)ISO(I),(AT(J,I),J=1,IC)                                   REFS   105
          IF(III.LE.1)GO TO 910                                               REFS   106
```

```
      MM=MM+1
      IF(MM.LE.MC)GO TO 121                                             REFS  107
      REWIND 10                                                         REFS  108
      RETURN                                                            REFS  109
  910 IF(NORF.NE.1)GO TO 9913                                           REFS  110
      READ(5,15)(P(J),J=1,15)                                           REFS  111
      READ(5,34)(RES(J),J=1,NCHCU)                                      REFS  112
      CALL PHOTO(RES,XO,NCULL,NCUUL,0,511,AREA)                         REFS  113
      IF(CUDEC.EQ.0.)GO TO 263                                          REFS  114
      AREA=AREA*EXP(CUDEC*ALOG(2.)/FRRHL)                               REFS  115
  263 WRITE(6,36)AREA                                                   REFS  116
      FACT=1.0                                                          REFS  117
      IF(NFAC(I).GT.1)GO TO 4022                                        REFS  118
      XL=ALOG(2.)/H(I)                                                  REFS  119
      TB=DECA -ALOG((1.-EXP(-XL*COUN ))/(COUN *XL))/XL                  REFS  120
      FACT=EXP(XL*TB)                                                   REFS  121
 4022 XN=AREA*WT/(WTCU*CJCT*1.0E+06*FACT)                               REFS  122
      DO 3019 J=1,ISOCHN                                                REFS  123
      XNORM(I)=XN*COUN                                                  REFS  124
 3019 AT(J,I)=AT(J,I)/(XNORM(I))                                        REFS  125
      WRITE(6,39)O(I)                                                   REFS  126
      WRITE(6,18)ISOCHN,(AT(J,I),J=1,ISOCHN)                            REFS  127
      IF(NO.LE.1)GO TO 9913                                             REFS  128
      MODE=1                                                            REFS  129
      DO 913 K=1,NO                                                     REFS  130
      DO 912 J=1,ISOCHN                                                 REFS  131
  912 CT(J,K)=CT(J,K)/XNORM(I)                                          REFS  132
      IF(NW.EQ.0)GO TO 913                                              REFS  133
      NORF=0                                                            REFS  134
      MODE=1                                                            REFS  135
      WRITE(2,24)O(I),ISO(I),NPK,LPP,NORF,MODE,NFAC(I),NO               REFS  136
      WRITE(2,51)H(I),D(I),FRRHL,XNORM(I)                               REFS  137
      WRITE(2,11)(CT(J,K),J=1,ISOCHN)                                   REFS  138
  913 CONTINUE                                                          REFS  139
 9913 IF(III.GT.1)GO TO 122                                             REFS  140
      IF(NORF.EQ.1)GO TO 911                                            REFS  141
      IF(NO.LE.1)GO TO 121                                              REFS  142
  911 NORF=0                                                            REFS  143
      MODE=1                                                            REFS  144
      WRITE(2,24)O(I),ISO(I),NPK,LPP,NORF,MODE,NFAC(I),NO               REFS  145
      WRITE(2,51)H(I),D(I),FRRHL,XNORM(I)                               REFS  146
      WRITE(2,11)(AT(J,I),J=1,ISOCHN)                                   REFS  147
  121 CONTINUE                                                          REFS  148
  122 WRITE(10)T,C,CT,NO,AT,ISO                                         REFS  149
      REWIND 10                                                         REFS  150
      RETURN                                                            REFS  151
      END                                                               REFS  152
      SUBROUTINE REFIN(AT,III,T,C,CT,NO,M,DECAY,COUNT,ISO,RHO,A)        REFS  153
      DIMENSIONAT(400,15),CT(400,5),T(5),C(5),ISO(15),IS(15),RHO(400),A(REFN   1
     1400)                                                              REFN   2
      USES THE LAGRANGE METHOD TO INTERPOLATE BETWEEN SPECTRA           REFN   3
      ISOCHN=ISO(M)                                                     REFN   4
      IF(III.LE.1)GO TO 154                                             REFN   5
      ISOCHN=IS(M)                                                      REFN   6
      READ(10)T,C,CT,NO,AT,ISO                                          REFN   7
  154 X=DECAY+COUNT/2.                                                  REFN   8
      DO 150 I=1,NO                                                     REFN   9
  150 T(I)=T(I)+C(I)/2.                                                 REFN  10
      DO 151 I=1,ISOCHN                                                 REFN  11
      AT(I,M)=0.                                                        REFN  12
      DO 152 J=1,NO                                                     REFN  13
      CT(I,J)=CT(I,J)/C(J)                                              REFN  14
      XNUM=1.0                                                          REFN  15
      XDEN=1.0                                                          REFN  16
      DO 153 L=1,NO                                                     REFN  17
      IF(L.EQ.J)GO TO 153                                               REFN  18
      XNUM=XNUM*(X-T(L))                                                REFN  19
      XDEN=XDEN*(T(J)-T(L))                                             REFN  20
  153 CONTINUE                                                          REFN  21
  152 AT(I,M)=XNUM*CT(I,J)/XDEN+AT(I,M)                                 REFN  22
  151 CONTINUE                                                          REFN  23
      IS(M)=ISOCHN                                                      REFN  24
      RETURN                                                            REFN  25
      END                                                               REFN  26
      SUBROUTINE PHOTO(RES,XO,IPPLL,IPPUL,EPP,AREA)                     REFN  27
      DIMENSION B(3),Q(15,15),RES(400),RE(3),B2(50),C(10)              FOTO   1
    4 FORMAT(35H LOWER LIMIT OF PHOTOPEAK FROM CHAN,I3,8H TO CHAN,I3,/3 FOTO   2
     15H UPPER LIMIT OF PHOTOPEAK FROM CHAN,I3,8H TO CHAN,I3)           FOTO   3
    9 FORMAT( //30H EXPERIMENTAL PHOTOPEAK POINTS /)                    FOTO   4
   10 FORMAT( //28H CALCULATED PHOTOPEAK POINTS /)                      FOTO   5
   15 FORMAT(1X,5E14.7)                                                 FOTO   6
   16 FORMAT(//2X,4HE,I3,2HXO,13X,2HBO,15X,2HYO,13X,4HAREA )           FOTO   7
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   17 FORMAT(F6.3,7X,F8.3,7X,F8.5,7X,E12.5,7X,E12.5 )              FOTO   9
   18 FORMAT(9X,4H+OR=,F8.3,3X,4H+OR=,F8.3,3X,4H+OR=,E12.5,3X,4H+OR=,E12FOTO  10
     1.5 )                                                         FOTO  11
      F(X)=YO*EXP(=((X=XO)**2)/BO)                                 FOTO  12
      IPPLO=IPPLL                                                  FOTO  13
      IPPUO=IPPUL                                                  FOTO  14
  212 XN=0.                                                        FOTO  15
      DO321 I=1,3                                                  FOTO  16
      B(I)=0.                                                      FOTO  17
      DO321 J=1,3                                                  FOTO  18
  321 Q(I,J)=0.                                                    FOTO  19
      DO 30 I=IPPLL,IPPUL                                          FOTO  20
      XN2=XN*XN                                                    FOTO  21
      XN3=XN2*XN                                                   FOTO  22
      XN4=XN3*XN                                                   FOTO  23
      ZN=ALOG(  RES(I))                                            FOTO  24
      Q(1,1)=Q(1,1)+XN4*RES(I)                                     FOTO  25
      Q(1,2)=Q(1,2)+XN3*RES(I)                                     FOTO  26
      Q(1,3)=Q(1,3)+XN2*RES(I)                                     FOTO  27
      Q(2,3)=Q(2,3)+XN*RES(I)                                      FOTO  28
      Q(3,3)=Q(3,3)+RES(I)                                         FOTO  29
      B(1)=B(1)+XN2*ZN*RES(I)                                      FOTO  30
      B(2)=B(2)+XN*ZN*RES(I)                                       FOTO  31
      B(3)=B(3)+ZN*RES(I)                                          FOTO  32
   30 XN=XN+1.                                                     FOTO  33
      Q(2,1)=Q(1,2)                                                FOTO  34
      Q(3,1)=Q(1,3)                                                FOTO  35
      Q(2,2)=Q(1,3)                                                FOTO  36
      Q(3,2)=Q(2,3)                                                FOTO  37
      CALL SMINV(Q,3)                                              FOTO  38
      DO1106 J=1,3                                                 FOTO  39
      RE(J)=0.                                                     FOTO  40
      DO1106 I=1,3                                                 FOTO  41
 106  RE (J)=RE (J)+Q(J,I)*B(I)                                    FOTO  42
      XO=(=RE(2)/(2.*RE(1)))                                       FOTO  43
      BO=-1./RE(1)                                                 FOTO  44
      YO=EXP(XO*XO/BO+RE(3))                                       FOTO  45
      IF(BO.LT.0.)BO=ABS(BO)                                       FOTO  46
      AREA=SQRT(3.1416*BO)*YO                                      FOTO  47
      XO=XO+FLOAT(IPPLL)                                           FOTO  48
      DO 80 I=1,3                                                  FOTO  49
  80  B(I)=RE(I)                                                   FOTO  50
      N=0                                                          FOTO  51
      RESI=0                                                       FOTO  52
      STDE=0                                                       FOTO  53
      XN=0                                                         FOTO  54
      DO 40 I=IPPLL,IPPUL                                          FOTO  55
      STDE=STDE+((ALOG(  RES(I))-B(3)-B(2)*XN-B(1)*XN*XN)**2)      FOTO  56
      RESI=RESI+(  RES(I)-F(FLOAT(I)))**2                          FOTO  57
   40 XN=XN+1.                                                     FOTO  58
      IF(RESI.LT.0.)RESI=ABS(RESI)                                 FOTO  59
      STDE=SQRT(RESI/FLOAT(IPPUL-IPPLL-2))                         FOTO  60
      IF(1.5*STDE.GT.ABS(  RES(IPPLL)-F(FLOAT(IPPLL))))GO TO 50    FOTO  61
      IPPLL=IPPLL+1                                                FOTO  62
      N=1                                                          FOTO  63
   50 IF(STDE.GT.ABS(  RES(IPPUL)-F(FLOAT(IPPUL))))GO TO 60        FOTO  64
      IPPUL=IPPUL-1                                                FOTO  65
      N=1                                                          FOTO  66
   60 IF(N.EQ.1)GO TO 212                                          FOTO  67
      IF(IPPLO.NE.IPPLL)GO TO 70                                   FOTO  68
      IF(IPPUO.EQ.IPPUL)GO TO 71                                   FOTO  69
   70 WRITE(6,4)IPPLO,IPPLL,IPPUO,IPPUL                            FOTO  70
   71 ZN=1./(4.*B(1)**2)                                           FOTO  71
      XN=(B(2)/B(1))**2                                            FOTO  72
      XN2=1./(B(1)**4)                                             FOTO  73
      XN3=XN/4.                                                    FOTO  74
C     THE FOLLOWING STATEMENT HAS BEEN CHANGED BY THE ENEA CPL SO THAT IT
C     CORRESPONDS TO THE FORMULA WHICH IS IN THE REPORT.
C     XN4=(XN**2)/FLOAT(NCHN)                                      FOTO  75
      XN4=(XN**2)/16.                                              FOTO  76
      C(1)=ZN*(Q(2,2)+XN*Q(1,1))                                  FOTO  77
      C(2)=XN2*Q(1,1)                                              FOTO  78
      C(3)=(YO**2)*(Q(3,3)+XN3*Q(2,2)+XN4*Q(1,1))                 FOTO  79
      C(4)=3.1416*(BO*C(3)+C(2)*YO**2/(2.*BO))                    FOTO  80
      DO 100 I=1,4                                                 FOTO  81
  100 C(I)=SQRT(C(I))                                              FOTO  82
      WRITE(6,16)                                                  FOTO  83
      WRITE(6,17)EPP,XO,BO,YO,AREA                                 FOTO  84
      WRITE(6,18)C(1),C(2),C(3),C(4)                              FOTO  85
      RETURN                                                      FOTO  86
      END                                                          FOTO  87
      SUBROUTINE SHIFT(NCHN,NPK,LPP,NWRITE,Y,PO)                   SHFT   1
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      DIMENSIONY(400),IXO(15),X(15),E(15),XP(15),RES(400)       SHFT    2
   10 FORMAT( 6X,12F6.0,2X )                                     SHFT    3
   11 FORMAT( 10I3 )                                             SHFT    4
   12 FORMAT( 4(I3,7X,F10.0) )                                   SHFT    5
   16 FORMAT( 8E10.0 )                                           SHFT    6
   26 FORMAT (/1X,12H OLD GAIN = ,E14.7,13H INTERCEPT = ,E14.7/  SHFT    7
     11X,18H BASE LINE SHFT = ,E14.7,12H NEW GAIN = ,E14.7,9H RATIO = , SHFT 8
     2E14.7/)                                                    SHFT    9
   42 FORMAT( I4,(1X,10E12.5) )                                  SHFT   10
   44 FORMAT(1H1,1X,17HNON SHIFTED SPECT ,3X,A4 )                SHFT   11
   45 FORMAT(  1X,13HSHIFTED SPECT  ,3X,A4 )                     SHFT   12
   47 FORMAT( 5E14.8 )                                           SHFT   13
   48 FORMAT( 1H1 )                                              SHFT   14
      WRITE(6,48)                                                SHFT   15
      READ(5,16)GAIN                                             SHFT   16
      READ(5,12)(IXO(I),E(I),I=1,NPK)                            SHFT   17
         IXO = APPROX MID PT OF PP                               SHFT   18
         E = ENERGY OF GAMMA PP                                  SHFT   19
      DO 100 I=1,NPK                                             SHFT   20
      IPPLL=IXO(I)-3                                             SHFT   21
      IPPUL=IXO(I)+3                                             SHFT   22
      CALL PHOTO(Y,XO,IPPLL,IPPUL,E(I),AREA)                     SHFT   23
  100 X(I)=XO                                                    SHFT   24
      IF(NPK.GT.1)GO TO 800                                      SHFT   25
      B1=E(1)/X(1)                                               SHFT   26
      BLSHFT=0.                                                  SHFT   27
  800 XNPK=NPK                                                   SHFT   28
      EM=0.                                                      SHFT   29
      XM=0.                                                      SHFT   30
      IF(NPK.EQ.1)GO TO 103                                      SHFT   31
      DO 807 J=1,NPK                                             SHFT   32
      EM=EM+E(J)                                                 SHFT   33
  807 XM=XM+X(J)                                                 SHFT   34
      EM=EM/XNPK                                                 SHFT   35
      XM=XM/XNPK                                                 SHFT   36
      TP=0.                                                      SHFT   37
      BT=0.                                                      SHFT   38
      DO 808 J=1,NPK                                             SHFT   39
      TP=TP+(X(J)-XM)*(E(J)-EM)                                  SHFT   40
  808 BT=BT+(X(J)-XM)**2                                         SHFT   41
      B1=TP/BT                                                   SHFT   42
      EO=EM-B1*XM                                                SHFT   43
      IF(NPK.EQ.1)GO TO 103                                      SHFT   44
      BLSHFT=-EO/B1                                              SHFT   45
  103 RATIO=(E(LPP)-EO)/(GAIN*X(LPP))                            SHFT   46
      WRITE(6,26)B1,EO,BLSHFT,GAIN,RATIO                         SHFT   47
      DO 809 J=1,NPK                                             SHFT   48
  809 XP(J)=RATIO*(X(J)-BLSHFT)                                  SHFT   49
      NCHN2=FLOAT(NCHN)*RATIO+0.5                                SHFT   50
      CALL SHIFTS(Y,RES,RATIO,NCHN,NCHN2,BLSHFT)                 SHFT   51
      DO 900 I=1,NPK                                             SHFT   52
      IPPLL=XP(I)-3.                                             SHFT   53
      IPPUL=XP(I)+5.                                             SHFT   54
      CALL PHOTO(RES,XO,IPPLL,IPPUL,E(I),AREA)                   SHFT   55
  900 CONTINUE                                                   SHFT   56
      WRITE(6,44)PO                                              SHFT   57
      WRITE(6,42)NCHN,(Y(J),J=1,NCHN)                            SHFT   58
      WRITE(6,45)PO                                              SHFT   59
      WRITE(6,42)NCHN2,(RES(J),J=1,NCHN2)                        SHFT   60
      NCHN=NCHN2                                                 SHFT   61
      DO 905 I=1,NCHN                                            SHFT   62
  905 Y(I)=RES(I)                                                SHFT   63
      IF(NWRITE.EQ.0)RETURN                                      SHFT   64
      WRITE(2,45)PO                                              SHFT   65
      WRITE(2,47)(RES(J),J=1,NCHN2)                              SHFT   66
      RETURN                                                     SHFT   67
      END                                                        SHFT   68
      SUBROUTINE SHIFTS(SPECT,S,RATIO,NCHN,NCHN2,BLSHFT)         SHIF    1
      DIMENSION SPECT(400),S(400)                                SHIF    2
      X=0.                                                       SHIF    3
      I1=0                                                       SHIF    4
***   TEST DATA FOR ZERO COUNTS IN CHANNELS 1,2,OR 3            SHIF    5
      IF(SPECT(1).NE.0.)GO TO 20                                 SHIF    6
      SPECT(1)=SPECT(2)                                          SHIF    7
   20 IF(SPECT(2).NE.0.)GO TO 21                                 SHIF    8
      SPECT(1)=SPECT(3)                                          SHIF    9
      SPECT(2)=SPECT(3)                                          SHIF   10
   21 IF(SPECT(3).NE.0.)GO TO 22                                 SHIF   11
      SPECT(1)=SPECT(4)                                          SHIF   12
      SPECT(2)=SPECT(4)                                          SHIF   13
      SPECT(3)=SPECT(4)                                          SHIF   14
***   FIT 3 POINTS OF SPECTRUM WITH PARABOLA AND EVALUATE       SHIF   15
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22    X=Y+1.
      I1=I1+1
      XP=(X/RATIO)+RLSHFT
      IF(XP.LE.1.)GO TO 24
      IF(XP.GE.2.)GO TO 25
      GO TO 26
24    S(I1)=SPECT(1)/RATIO
      GO TO 22
26    X1=1.
      X2=2.
      X3=3.
      Y1=SPECT(1)
      Y2=SPECT(2)
      Y3=SPECT(3)
      GO TO 27
25    IX2=XP+.5
      IF(IX2.GE.NCHN)GO TO 28
      IX1=IX2-1
      IX3=IX2+1
      Y1=SPECT(IX1)
      Y2=SPECT(IX2)
      Y3=SPECT(IX3)
      X1=IX1
      X2=IX2
      X3=IX3
27    AA=(Y3-2.*Y2+Y1)/2.
      BB=(-Y3*(X2+X1)+2.*Y2*(X1+X3)-Y1*(X3+X2))/2.
      CC=((X1*X2*Y3)-2.*(X1*X3*Y2)+(X2*X3*Y1))/2.
28    S(I1)=(AA*XP*XP+BB*XP+CC)/RATIO
      IF(S(I1).LT.0.)S(I1)=0.0
      IF(I1.LT.NCHN2)GO TO 22
      RETURN
      END
      SUBROUTINE WRIT1(O,BETA,STDEV,NISO)
      DIMENSION O(15),BETA(15),STDEV(15)
40    FORMAT(8X,6(4X,A4,4X))
42    FORMAT( 8HSOL(PPM),6(E12.4))
43    FORMAT( 8HSTD DEV ,6(E12.4))
      LO=1
      MAX=6
44    IF(NISO.LT.MAX)MAX=NISO
      WRITE(2,40)(O(I),I=LO,MAX)
      WRITE(2,42)(BETA(I),I=LO,MAX)
      WRITE(2,43)(STDEV(I),I=LO,MAX)
      IF(NISO.EQ.MAX)GO TO 50
      LO=LO+6
      MAX=MAX+6
      GO TO 44
50    RETURN
      END
      SUBROUTINE VARNCE(A,OMG,STDEV,AT,LOCHN,NHICHN,NISO,MAXCON,C,P,O,BETA,XNORM)
      DIMENSION RES(400),OMG(400),STDEV(400),AT(400,15),P(15),O(15),BETA(15),C(15),A(400),XNORM(15)
      DO 105 J=LOCHN,NHICHN
105   RES(J)=0.0
      K=1
      DO 101 I=1,MAXCON
      IF(P(I).NE.O(K))GO TO 101
      DO 102 J=LOCHN,NHICHN
102   RES(J)=RES(J)+((BETA(K)/C(K))**2)*AT(I,I)/XNORM(I)+(AT(J,I)*STDEV(K)/C(K))**2
      K=K+1
      IF(K.GT.NISO)GO TO 103
101   CONTINUE
103   DO 104 J=LOCHN,NHICHN
104   A(J)=OMG(J)+RES(J)
      RETURN
      END
      SUBROUTINE DELETE(NISO,REMOVE,ISOCHN,BETA,R,C,O,THETA,L)
      DIMENSION RES(400),BETA(15),C(15),O(15),THETA(15),R(15,15)
30    FORMAT(/17H ISOTOPE REMOVED , A4 /)
      WRITE(6,30)O(L)
      NISO=NISO-1
      BETAR=BETA(L)/C(L)
      DO 601 J=1,ISOCHN
601   RES(J)=R(J,L)
      REMOVE=REMOVE-(BETA(L)/C(L))**2/R(L,L)
      DO 604 K=1,NISO
      BETA(K)=(BETA(K)/C(K)-RES(K)*BETAR/RES(L))*C(K)
      DO 604 J=1,NISO
604   R(K,J)=R(K,J)-RES(K)*RES(J)/RES(L)
```

```
      DO 602 K=L,NISO                                          DELT  14
      O(K)=O(K+1)                                              DELT  15
      THETA(K)=THETA(K+1)                                      DELT  16
      BETA(K)=BETA(K+1)                                        DELT  17
      DO 602 J=1,ISOCHN                                        DELT  18
  602 R(J,K)=R(J,K+1)                                          DELT  19
      DO 603 K=L,NISO                                          DELT  20
      DO 603 J=1,NISO                                          DELT  21
  603 R(K,J)=R(K+1,J)                                          DELT  22
      RETURN                                                   DELT  23
      END                                                      DELT  24
      SUBROUTINE DET(R,N,DETERM)                               DELT  25
      DIMENSION R(15,15)                                       DETR   1
C     DETERMINANT  EVALUATED USING PIVOTAL CONDENSATION        DETR   2
      K = 2                                                    DETR   3
      L = 1                                                    DETR   4
    5 DO 20 I=K,N                                              DETR   5
      RATIO = R(I,L)/R(L,L)                                    DETR   6
      DO 20 J=K,N                                              DETR   7
      R(I,J) = R(I,J)-R(L,J)*RATIO                             DETR   8
   20 CONTINUE                                                 DETR   9
      IF(K-N) 15,21,21                                         DETR  10
   15 L = K                                                    DETR  11
      K = K+1                                                  DETR  12
      GO TO 5                                                  DETR  13
   21 DETERM = 1.                                             DETR  14
      DO 25 L=1,N                                              DETR  15
   25 DETERM = DETERM*R(L,L)                                   DETR  16
      RETURN                                                   DETR  17
      END                                                      DETR  18
      SUBROUTINE WRIT(NITER,ITER,O,BETA,STDEV,ST,NISO,F,RCORR) DETR  19
      DIMENSION O(15),BETA(15),STDEV(400),ST(15)              WRIT   1
   40 FORMAT(/10X,10(4X,A4,4X))                                WRIT   2
   41 FORMAT(/1H ,ITERATION,I3,4H OF ,I3,9H MAX ITER /)        WRIT   3
   42 FORMAT(10H SOL (PPM) ,10(E12.4))                         WRIT   4
   43 FORMAT(10H STD DEV  ,10(E12.4))                          WRIT   5
   44 FORMAT(10H T VALUES ,10(E12.4))                          WRIT   6
   45 FORMAT(/12HL F VALUE = ,E11.4,14H  CORR COEF = ,E11.4/)  WRIT   7
      WRITE(6,41)NITER,ITER                                    WRIT   8
      MAX=NISO                                                 WRIT   9
      IF(NISO.LE.10)GO TO 4450                                 WRIT  10
      MAX=10                                                   WRIT  11
 4450 WRITE(6,40)(O(I),I=1,MAX)                                WRIT  12
      WRITE(6,42)(BETA(I),I=1,MAX)                             WRIT  13
      WRITE(6,43)(STDEV(I),I=1,MAX)                            WRIT  14
      WRITE(6,44)(ST(I),I=1,MAX)                               WRIT  15
      IF(NISO.LE.10)GO TO 4451                                 WRIT  16
      WRITE(6,40)(O(I),I=11,NISO)                              WRIT  17
      WRITE(6,42)(BETA(I),I=11,NISO)                           WRIT  18
      WRITE(6,43)(STDEV(I),I=11,NISO)                          WRIT  19
      WRITE(6,44)(ST(I),I=11,NISO)                             WRIT  20
 4451 WRITE(6,45)F,RCORR                                       WRIT  21
      RETURN                                                   WRIT  22
      END                                                      WRIT  23
      SUBROUTINE SAVE(NISO,O,OI,RI,RII)                        WRIT  24
      DIMENSION O(15),OI(15),RI(15,15),RII(15,15)             SAVE   1
      DO 3180 I=1,NISO                                         SAVE   2
      OI(I)=O(I)                                               SAVE   3
      DO 3180 J=1,NISO                                         SAVE   4
 3180 RII(I,J)=RI(I,J)                                         SAVE   5
      RETURN                                                   SAVE   6
      END                                                      SAVE   7
      SUBROUTINE XFORM(NFORM,NISO,R,RI,MAXCON,P,O,LOCHN,NHICHN,A,AT,NCORFORM   1
     1,NWRIT,NIDEN,NINT,RII,BETA,THETA,OI,RHO,III)             FORM   2
      DIMENSION R(15,15),RI(15,15),RII(15,15),P(15),O(15),A(400),AT(400,FORM   3
     115),OI(15),Q(15,15),S(15,15),BETA(15),THETA(15),RHO(400) FORM   4
C         THIS SUB. FORMS OR READS  A-TRANS * W * A             FORM   5
    9 FORMAT( 1H1 )                                            FORM   6
   18 FORMAT( I4,(1X, 10E12.5) )                               FORM   7
   22 FORMAT( 1X,A4,(1X,5E12.5))                               FORM   8
   23 FORMAT( /18H CORRELATION COEFF /)                        FORM   9
   25 FORMAT( /26H INTERFERENCES IN PER CENT / )               FORM  10
   29 FORMAT(/ 21H CROSS PRODUCT MATRIX / )                    FORM  11
      FORMAT( 3F24.18 )                                        FORM  12
   31 FORMAT(/ 25H INV CROSS PRODUCT MATRIX /)                 FORM  13
   32 FORMAT(/ 16H IDENTITY MATRIX /)                          FORM  14
   33 FORMAT(/13H INV ERROR = ,E14.7 /)                        FORM  15
   37 FORMAT(/ 20 H EFF(IN PER CENT) = ,E18.12 / )             FORM  16
   39 FORMAT(/6X,9(4X,A4,4X))                                  FORM  17
   40 GO TO (98,99,40),NFORM                                   FORM  18
      CALL PEAKS(AT,A,RHO,LOCHN,NHICHN,NISO,III)               FORM  19
```

```
   98 READ(5,29)((R(I,J),I=1,NISO),J=1,NISO)                         FORM  20
      CALL SAVE(NISO,0,OI,R,RII)                                      FORM  21
      GO TO 322                                                       FORM  22
   99 DO 102 J=1,NISO                                                 FORM  23
      DO 102 I=1,NISO                                                 FORM  24
      RI(I,J)=0.                                                      FORM  25
  102 R(I,J)=0.                                                       FORM  26
      LL=1                                                            FORM  27
      DO 4052 J=1,MAXCON                                              FORM  28
      IF(P(J).NE.O(LL))GO TO 4052                                     FORM  29
      L=1                                                             FORM  30
      DO 4053 K=1,MAXCON                                              FORM  31
      IF(P(K).NE.O(L))GO TO 4053                                      FORM  32
      DO 100 I=LOCHN,NHICHN                                           FORM  33
      IF(A(I).LE.0.001)A(I)=1.0                                       FORM  34
  100 R(LL,L)=R(LL,L)+AT(I,J)*AT(I,K)/A(I)                            FORM  35
      L=L+1                                                           FORM  36
      IF(L.GT.NISO)GO TO 4054                                         FORM  37
 4053 CONTINUE                                                        FORM  38
 4054 LL=LL+1                                                         FORM  39
      IF(LL.GT.NISO)GO TO 4055                                        FORM  40
 4052 CONTINUE                                                        FORM  41
 4055 WRITE(6,23)                                                     FORM  42
      IF(NCORR.NE.0) GO TO 97                                         FORM  43
      WRITE(6,23)                                                     FORM  44
      DO 311 J=1,NISO                                                 FORM  45
      DO 311 I=1,NISO                                                 FORM  46
  311 RI(J,I)=(R(I,J)**2)/(R(I,I)*R(J,J))                             FORM  47
      WRITE(6,18)NISO,((RI(I,J),I=1,NISO),J=1,NISO)                   FORM  48
      CALL DET(RI,NISO,DETERM)                                        FORM  49
      DETERM=100.*DETERM                                              FORM  50
      WRITE(6,37)DETERM                                               FORM  51
   97 CALL SAVE(NISO,0,OI,R,RII)                                      FORM  52
      IF(NWRIT.NE.0) GO TO 107                                        FORM  53
      WRITE(6,9)                                                      FORM  54
      WRITE(6,28)                                                     FORM  55
      WRITE(6,18)NISO,((R(I,J),I=1,NISO),J=1,NISO)                    FORM  56
  107 CALL SMINV(R,NISO)                                              FORM  57
      IF(NWRIT.NE.0) GO TO 313                                        FORM  58
      WRITE(6,31)                                                     FORM  59
      WRITE(6,18)NISO,((R(I,J),I=1,NISO),J=1,NISO)                    FORM  60
      CALL SAVE(NISO,OI,0,RII,RI)                                     FORM  61
      CALL SAVE(NISO,0,OI,R,RII)                                      FORM  62
  313 IF(NIDEN.NE.0)GO TO 322                                         FORM  63
      LL=0                                                            FORM  64
 4001 ERROR=0.                                                        FORM  65
      DO 324 K=1,NISO                                                 FORM  66
      DO 324 J=1,NISO                                                 FORM  67
      Q(K,J)=0.                                                       FORM  68
      DO 324 I=1,NISO                                                 FORM  69
  324 Q(K,J)=Q(K,J)+RI(K,I)*R(I,J)                                    FORM  70
      DO 323 K=1,NISO                                                 FORM  71
      DO 323 J=1,NISO                                                 FORM  72
  323 ERROR=ERROR+ABS(Q(K,J))                                         FORM  73
      ERROR=(ERROR-FLOAT(NISO))/((FLOAT(NISO))**2)                    FORM  74
      IF(LL.GT.3)GO TO 3360                                           FORM  75
      IF(ERROR.LT.0.000050)GO TO 3360                                 FORM  76
  *** ITERATE TO IMPROVE ACC                                         FORM  77
      DO 127 I=1,NISO                                                 FORM  78
      DO 127 J=1,NISO                                                 FORM  79
  127 S(I,J)=-Q(I,J)                                                  FORM  80
      DO 128 J=1,NISO                                                 FORM  81
  128 S(J,J)=2.0+S(J,J)                                               FORM  82
      DO 129 K=1,NISO                                                 FORM  83
      DO 129 J=1,NISO                                                 FORM  84
      Q(K,J)=0.0                                                      FORM  85
      DO 129 I=1,NISO                                                 FORM  86
  129 Q(K,J)=Q(K,J)+R(K,I)*S(I,J)                                     FORM  87
      DO 130 J=1,NISO                                                 FORM  88
      DO 130 K=1,NISO                                                 FORM  89
  130 R(K,J)=Q(K,J)                                                   FORM  90
      LL=LL+1                                                         FORM  91
      GO TO 4001                                                      FORM  92
 3360 WRITE(6,33)ERROR                                                FORM  93
      WRITE(6,32)                                                     FORM  94
      WRITE(6,18)NISO,((Q(J,K),J=1,NISO),K=1,NISO)                    FORM  95
  322 IF(NINTF.NE.0)RETURN                                            FORM  96
      WRITE(6,9)                                                      FORM  97
      WRITE(6,25)                                                     FORM  98
      MIN=2                                                           FORM  99
      MAX=NISO-1                                                      FORM 100
```

```
      DO 315 I=1,MAX                                              FORM 102
      DO 316 J=MIN,NISO                                           FORM 103
      BETA(J)=O(J)                                                FORM 104
316   THETA(J)=((R(I,J)**2)/(R(I,I)*R(J,J)))*100.                 FORM 105
      WRITE(6,39)(BETA(J),J=MIN,NISO)                             FORM 106
      WRITE(6,22)O(I),(THETA(J),J=MIN,NISO)                       FORM 107
315   MIN=MIN+1                                                   FORM 108
      RETURN                                                      FORM 109
      END                                                         FORM 110
      SUBROUTINE WATE(NVAR,NUMVAR,NCHAN,RHO,XNCOM,III,OMG,A,RES,ISOCHN)  WATE 1
      DIMENSION RES(400),RHO(400),OMG(400),A(400)                 WATE 2
11    FORMAT( 5E14.8 )                                            WATE 3
47    FORMAT(/22H AVE WT FACTORS--USES ,I3,6H IN NO  /)           WATE 4
48    FORMAT(/19H WT FACTORS = UNITY /)                           WATE 5
49    FORMAT(/15H WT FACTORS = Y  /)                              WATE 6
      THIS SUB CALCULATES OR READS THE WT FACTORS                 WATE 7
      READ OR SET VARIANCES USING (A) AS STORAGE                  WATE 8
      GO TO (201,203,3010),NVAR                                   WATE 9
201   DO 2202 J=1,400                                             WATE 10
2202  RES(J)=0.0                                                  WATE 11
      WRITE(6,47)NUMVAR                                           WATE 12
      DO 2201 J=1,NUMVAR                                          WATE 13
      READ(5,11)(A(I),I=1,NCHAN)                                  WATE 14
      DO 2222 K=1,NCHAN                                           WATE 15
2222  RES(K)=RES(K)+A(K)                                          WATE 16
2201  CONTINUE                                                    WATE 17
      DO 2224 I=1,NCHAN                                           WATE 18
2224  RES(I)=RES(I)/FLOAT(NUMVAR)                                 WATE 19
      WRITE(2,11)(RES(I),I=1,NCHAN)                               WATE 20
      DO 2223 I=1,NCHAN                                           WATE 21
2223  A(I)=RES(I)                                                 WATE 22
      GO TO 205                                                   WATE 23
203   DO 213 I=1,ISOCHN                                           WATE 24
213   A(I)=1.0                                                    WATE 25
      WRITE(6,48)                                                 WATE 26
      GO TO 205                                                   WATE 27
3010  DO 3014 I=1,ISOCHN                                          WATE 28
3014  A(I)=RHO(I)/XNCOM                                           WATE 29
      IF(A(I).EQ.0.)A(I)=1.0                                      WATE 30
      WRITE(6,49)                                                 WATE 31
205   IF(NVAR.EQ.2)GO TO 254                                      WATE 32
      IF(III.GT.1)GO TO 254                                       WATE 33
256   DO 255 I=1,ISOCHN                                           WATE 34
255   OMG(I)=A(I)                                                 WATE 35
254   CONTINUE                                                    WATE 36
      RETURN                                                      WATE 37
      END                                                         WATE 38
      SUBROUTINE CHI(CALC,RES,MAXCON,P,O,LOCHN,NHICHN,BETA,AT,C,RHO,NISO  CHI 1
     1,QUAL,A)                                                    CHI 2
      DIMENSION CALC(400),RES(400),P(15),O(15),BETA(15),AT(400,15),C(15),  CHI 3
     1RHO(400),A(400)                                             CHI 4
10    FORMAT(1X,2A4 )                                             CHI 5
14    FORMAT( 18H DEG OF FREEDOM = ,F4.0,15H QUAL OF FIT = ,E10.3) CHI 6
18    FORMAT(/I4,(1X, 10E12.5 ) )                                 CHI 7
      DO 105 I=LOCHN,NHICHN                                       CHI 8
      CALC(I)=0.                                                  CHI 9
105   RES(I)=0.                                                   CHI 10
      K=1                                                         CHI 11
      DO 956 I=1,MAXCON                                           CHI 12
      IF(P(I).NE.O(K))GO TO 956                                   CHI 13
      DO 970 J=LOCHN,NHICHN                                       CHI 14
970   CALC(J)=BETA(K)*AT(J,I)/C(K)+CALC(J)                        CHI 15
      K=K+1                                                       CHI 16
      IF(K.GT.NISO)GO TO 957                                      CHI 17
956   CONTINUE                                                    CHI 18
957   QUAL=0.                                                     CHI 19
      DO 104 I=LOCHN,NHICHN                                       CHI 20
104   RES(I)=RHO(I)-CALC(I)                                       CHI 21
      DO 971 J=LOCHN,NHICHN                                       CHI 22
971   QUAL=QUAL+(RES(J)**2)/A(J)                                  CHI 23
      QUAL=QUAL/FLOAT(NHICHN-LOCHN-NISO)                          CHI 24
      DF=NHICHN-LOCHN-NISO                                        CHI 25
      WRITE(6,14)DF,QUAL                                          CHI 26
      RETURN                                                      CHI 27
      END                                                         CHI 28
      SUBROUTINE PEAKS(AT,A,RHO,LOCHN,NHICHN,NISO,III)            PEAK 1
      DIMENSION AT(400,15),A(400),RHO(400),NK(40),T(5),C(5),CT(400,5),ISO PEAK 2
     1(15)                                                        PEAK 3
41    FORMAT(/ 14H COMPLEX SPECT /)                               PEAK 4
42    FORMAT( 25I3 )                                              PEAK 5
43    FORMAT( 1X,5E14.7 )                                         PEAK 6
      REWIND 10                                                   PEAK 7
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      IF(IIT.LE.1)GO TO 103                                        PEAK   8
      READ(10)T,C,CT,NO,AT,ISO                                     PEAK   9
103   READ(5,42)NPKS1,NREG                                         PEAK  10
      READ(5,42)(NK(I),I=1,NPKS1)                                  PEAK  11
      I=1                                                          PEAK  12
      DO 100 J=1,NPKS1                                             PEAK  13
      MM=NK(J)+NREG                                                PEAK  14
      M=NK(J)-NREG                                                 PEAK  15
      IF(J.EQ.1)GO TO 101                                          PEAK  16
      IF(M.GT.NK(J-1)+NREG)GO TO 101                               PEAK  17
      M=NK(J-1)+NREG+1                                             PEAK  18
101   A(I)=A(M)                                                    PEAK  19
      RHO(I)=RHO(M)                                                PEAK  20
      DO 102 JJ=1,NISO                                             PEAK  21
102   AT(I,JJ)=AT(M,JJ)                                            PEAK  22
      M=M+1                                                        PEAK  23
      I=I+1                                                        PEAK  24
      IF(M.LE.MM)GO TO 101                                         PEAK  25
100   CONTINUE                                                     PEAK  26
      LOCHN=1                                                      PEAK  27
      NHICHN=I-1                                                   PEAK  28
      WRITE(6,41)                                                  PEAK  29
      WRITE(6,43)(RHO(J),J=LOCHN,NHICHN)                           PEAK  30
      RETURN                                                       PEAK  31
      END                                                          PEAK  32
      SUBROUTINE SMINV(R,N)                                        SMIN   1
      DIMENSION A(230),R(15,15)                                    SMIN   2
6     FORMAT(28HKSINGULAR MATRIX TERMINATION)                      SMIN   3
      MIN=1                                                        SMIN   4
      K=0                                                          SMIN   5
      DO 101 I=1,N                                                 SMIN   6
      DO 102 J=MIN,N                                               SMIN   7
      K=K+1                                                        SMIN   8
102   A(K)=R(I,J)                                                  SMIN   9
101   MIN=MIN+1                                                    SMIN  10

C     OBTAIN THE INVERSE OF SYMMETRY MATRIX A OF ORDER N.  ONLY THE  SMIN  11
C        UPPER TRIANGULAR PART OF A IS STORED.  ON EXIT THE INVERSE  SMIN  12
C        REPLACES A IN STORAGE.  THE INVERSE MATRIX IS FOUND BY      SMIN  13
C        SUCCESSIVE CONGRUENT TRANSFORMATIONS TO OBTAIN THE DIAGONAL,SMIN  14
C        INVERTING THE DIAGONAL ELEMENTS AND PERFORMING THE CONGRUENTSMIN  15
C        TRANSFORMATIONS IN REVERSE GIVES THE INVERSE MATRIX.        SMIN  16
C                 (WITH INTERCHANGE)                                 SMIN  17

      I1=N*(N+1)/2+1                                               SMIN  20
      DO50I=1,N                                                    SMIN  21
      II=INDEX(I,I,N)                                              SMIN  22
      I4=I-1                                                       SMIN  23
      I4I=INDEX(I4,I,N)                                            SMIN  24
      IF (I.EQ.N) GO TO 77                                         SMIN  25
      IF (I.EQ.1) GO TO 32                                         SMIN  26
      A(I4I)=1.                                                    SMIN  27
      GO TO 34                                                     SMIN  28
32    A(I1)=1                                                      SMIN  29
34    AM=0.                                                        SMIN  30
      DO70 J=I,N                                                   SMIN  31
      JJ=INDEX(J,J,N)                                              SMIN  32
      IF(ABS(A(JJ)).LE.AM) GO TO 70                                SMIN  33
      AM=ABS(A(JJ))                                                SMIN  34
      IF(I.GT.1) GO TO 53                                          SMIN  35
      A(I1)=J                                                      SMIN  36
      GO TO 70                                                     SMIN  37
53    A(I4I)=J                                                     SMIN  38
70    CONTINUE                                                     SMIN  39
      IF (I.GT.1) GO TO 86                                         SMIN  40
      M=A(I1)                                                      SMIN  41
      GO TO 67                                                     SMIN  42
86    M = A(I4I)                                                   SMIN  43
67    IF(M.EQ.I) GO TO 77                                          SMIN  44
      DO 105 J=I,N                                                 SMIN  45
      IJ=INDEX(I,J,N)                                              SMIN  46
      JM=INDEX(J,M,N)                                              SMIN  47
      BB=A(IJ)                                                     SMIN  48
      A(IJ)=A(JM)                                                  SMIN  49
105   A(JM)=BB                                                     SMIN  50
      IM=INDEX(I,M,N)                                              SMIN  51
      BB=A(II)                                                     SMIN  52
      A(II)=A(IM)                                                  SMIN  53
      A(IM)=BB                                                     SMIN  54
77    IF(A(II).EQ.0.0) GO TO 300                                  SMIN  55
      A(II)=1./A(II)                                               SMIN  56
```

```
      IF(I.EQ.N) GO TO 60                                      SMIN  58
      JJ=I+1                                                    SMIN  59
      DO 72 K=JJ,N                                              SMIN  60
      IK=INDEX(I,K,N)                                           SMIN  61
      IF(I.GT.1) GO TO 62                                       SMIN  62
      I2=N*(I+1)/2+K                                            SMIN  63
      A(I2)=-A(II)*A(IK)                                        SMIN  64
      GO TO 72                                                  SMIN  65
   62 I4K=INDEX(I4,K,N)                                         SMIN  66
      A(I4K)=-A(II)*A(IK)                                       SMIN  67
   72 CONTINUE                                                  SMIN  68
      DO 120 J=JJ,N                                             SMIN  69
      DO 120 K=J,N                                              SMIN  70
      JK=INDEX(J,K,N)                                           SMIN  71
      IJ=INDEX(I,J,N)                                           SMIN  72
      IF (I.GT.1) GO TO 82                                      SMIN  73
      I2=N*(N+1)/2+K                                            SMIN  74
      A(JK)=A(JK)+A(I2)*A(IJ)                                   SMIN  75
      GO TO 120                                                 SMIN  76
   82 I4K=INDEX(I4,K,N)                                         SMIN  77
      A(JK)=A(JK)+A(I4K)*A(IJ)                                  SMIN  78
  120 CONTINUE                                                  SMIN  79
   60 CONTINUE                                                  SMIN  80
      DO 240 MM=2,N                                             SMIN  81
      I=N-MM+1                                                  SMIN  82
      I4=I-1                                                    SMIN  83
      I4I=INDEX(I4,I,N)                                         SMIN  84
      II=INDEX(I,I,N)                                           SMIN  85
      JJ=I+1                                                    SMIN  86
      DO 230 J=JJ,N                                             SMIN  87
      IJ=INDEX(I,J,N)                                           SMIN  88
  230 A(IJ)=0.0                                                 SMIN  89
      DO 220 J=JJ,N                                             SMIN  90
      I4J=INDEX(I4,J,N)                                         SMIN  91
      IJ=INDEX(I,J,N)                                           SMIN  92
      DO 180 K=J,N                                              SMIN  93
      I4K=INDEX(I4,K,N)                                         SMIN  94
      IK=INDEX(I,K,N)                                           SMIN  95
      JK=INDEX(J,K,N)                                           SMIN  96
      IF(I.EQ.1) GO TO 168                                      SMIN  97
      A(IK)=A(IK)+A(I4J)*A(JK)                                  SMIN  98
      IF(J.EQ.K) GO TO 180                                      SMIN  99
      A(IJ)=A(IJ)+A(I4K)*A(JK)                                  SMIN 100
      GO TO 180                                                 SMIN 101
  168 I2=N*(N+1)/2+K                                            SMIN 102
      I3=N*(N+1)/2+J                                            SMIN 103
      A(IK)=A(IK)+A(I3)*A(JK)                                   SMIN 104
      IF(J.EQ.K) GO TO 180                                      SMIN 105
      A(IJ)=A(IJ)+A(I2)*A(JK)                                   SMIN 106
  180 CONTINUE                                                  SMIN 107
      IF (I.EQ.1) GO TO 187                                     SMIN 108
      A(II)=A(II)+A(I4J)*A(IJ)                                  SMIN 109
      GO TO 220                                                 SMIN 110
  187 A(II)=A(II)+A(I3)*A(IJ)                                   SMIN 111
  220 CONTINUE                                                  SMIN 112
      IF(I.GT.1)GO TO 131                                       SMIN 113
      M=A(II)                                                   SMIN 114
      GO TO 143                                                 SMIN 115
  131 M=A(I4I)                                                  SMIN 116
  143 IF(M.EQ.I) GO TO 240                                      SMIN 117
      DO 105 J=I,N                                              SMIN 118
      IJ=INDEX(I,J,N)                                           SMIN 119
      JM=INDEX(J,M,N)                                           SMIN 120
      BB=A(IJ)                                                  SMIN 121
      A(IJ)=A(JM)                                               SMIN 122
  105 A(JM)=BB                                                  SMIN 123
      IM=INDEX(I,M,N)                                           SMIN 124
      BB=A(II)                                                  SMIN 125
      A(II)=A(IM)                                               SMIN 126
      A(IM)=BB                                                  SMIN 127
  240 CONTINUE                                                  SMIN 128
      MIN=1                                                     SMIN 129
      K=0                                                       SMIN 130
      DO 103 I=1,N                                              SMIN 131
      DO 104 J=MIN,N                                            SMIN 132
      K=K+1                                                     SMIN 133
  104 R(I,J)=A(K)                                               SMIN 134
  103 MIN=MIN+1                                                 SMIN 135
      MIN=2                                                     SMIN 136
      MAX=N-1                                                   SMIN 137
      DO 115 I=1,MAX                                            SMIN 138
      DO 106 J=MIN,N                                            SMIN 139
```

```
106  R(J,I)=R(I,J)                                                              SMIN  140
115  MIN=MIN+1                                                                  SMIN  141
     RETURN                                                                     SMIN  142
300  WRITE (3,6)                                                                SMIN  143
     STOP                                                                       SMIN  144
     END                                                                        SMIN  145
     FUNCTION INDEX(I8,J8,N)                                                     INDX   1
     FOR SYMMETRICAL MATRICES ONLY...                                           INDX   2
     THIS SUBPROGRAM ALLOWS THE PROGRAMMER TO REFER TO A TWO-DIMENSIONA INDX   3
     MATRIX WITH SUBSCRIPTS (I,J) WHILE THE MATRIX IS STORED AS A VECTO INDX   4
     I9= ROW OF MATRIX                                                          INDX   5
     JI= COLUMN OF MATRIX                                                       INDX   6
     N = ORDER OF MATRIX                                                        INDX   7
                                                                                INDX   8
     I9=I8                                                                      INDX   9
     JI=J8                                                                      INDX  10
     IF(I9.LE.JI)GO TO 2                                                        INDX  11
     J9=JI                                                                      INDX  12
     JI=I9                                                                      INDX  13
     I9=J9                                                                      INDX  14
  2  MI=0                                                                       INDX  15
     IF(I9.LT.2)GO TO 4                                                         INDX  16
     DO 5 LI=2,I9                                                               INDX  17
  5  MI=MI+N-LI                                                                 INDX  18
  4  INDEX=I9+JI-1+MI                                                           INDX  19
     RETURN                                                                     INDX  20
     END                                                                        INDX  21
     SUBROUTINE STAT(REMOVE,BETA,RHOSQD,NISO,LOCHN,NHICHN,R,C,O,AT,A,RES,STAT   1
    1RHO,NVAR,NR,RAT,ST,NITER,F,RCORR,P,MAXCON,RHOSUM,XNORM,MVAR,ISO,    STAT   2
    2IIT)                                                                       STAT   3
     DIMENSIONRES(400),BETA(15),R(15,15),C(15),O(15),AT(400,15),A(400), STAT   4
    1RHO(400),S2(15),ST(15),P(15),XNORM(15),ISO(15),ATT(400,15)                STAT   5
 28  FORMAT(/12H STD DEV OF ,A4,8H IS NEG /)                                    STAT   6
 34  FORMAT( 6X,12F6.0,2X )                                                     STAT   7
     IF(IIT.GT.1)GO TO 525                                                      STAT   8
     DO 526 J=1,MAXCON                                                          STAT   9
     DO 527 I=1,NHICHN                                                          STAT  10
527  ATT(I,J)=0.0                                                               STAT  11
     LI=ISO(J)                                                                  STAT  12
     DO 524 I=1,LI                                                              STAT  13
524  ATT(I,J)=AT(I,J)                                                           STAT  14
526  CONTINUE                                                                   STAT  15
525  VAREST=1.0                                                                 STAT  16
     RCORR=   REMOVE/RHOSQD                                                     STAT  17
     IF(RCORR.GT.0.9999)GO TO 502                                               STAT  18
     DF=FLOAT(NHICHN-LOCHN+1)                                                   STAT  19
     VAREST=(RHOSQD-RHOSUM/DF)/DF                                               STAT  20
502  IF(MVAR.EQ.0)GO TO 522                                                     STAT  21
     DO 523 J=1,NISO                                                            STAT  22
     LI=ISO(J)                                                                  STAT  23
523  READ(5,34)(ATT(I,J),I=1,LI)                                                STAT  24
522  DO 123 I=1,NISO                                                            STAT  25
     S2(I)=0.0                                                                  STAT  26
     L=1                                                                        STAT  27
     DO 122 J=1,MAXCON                                                          STAT  28
     IF(P(J).NE.O(L))GO TO 122                                                  STAT  29
     DO 102 K=LOCHN,NHICHN                                                      STAT  30
102  S2(I)=S2(I)+((R(I,L)*RHO(K)/A(K))**2)*ATT(K,J)/XNORM(J)                    STAT  31
     L=L+1                                                                      STAT  32
     IF(L.GT.NISO)GO TO 123                                                     STAT  33
122  CONTINUE                                                                   STAT  34
123  CONTINUE                                                                   STAT  35
     IF(NVAR.EQ.2)GO TO 100                                                     STAT  36
     IF(NITER.GT.0)GO TO 107                                                    STAT  37
     IF(NVAR.NE.3)GO TO 111                                                     STAT  38
     DO 103 I=1,NISO                                                            STAT  39
     IF(R(I,I).GE.0.)GO TO 104                                                  STAT  40
     WRITE(6,28)O(I)                                                            STAT  41
     R(I,I)=ABS(R(I,I))                                                         STAT  42
104  RES(I)=SQRT(R(I,I)+S2(I))*C(I)                                             STAT  43
103  ST(I)  =BETA(I)/RES(I)                                                     STAT  44
     IF(NVAR.EQ.3)GO TO 105                                                     STAT  45
111  IF(NR.EQ.0)GO TO 107                                                       STAT  46
     VAREST=RAT                                                                 STAT  47
     GO TO 100                                                                  STAT  48
107  DO 131 I=1,NISO                                                            STAT  49
     RES(I)=0.0                                                                 STAT  50
     M=1                                                                        STAT  51
     DO 119 J=1,MAXCON                                                          STAT  52
     IF(P(J).NE.O(M))GO TO 119                                                  STAT  53
     N=1                                                                        STAT  54
     DO 120 L=1,MAXCON                                                          STAT  55
```

```
      IF(P(L).NE.O(N))GO TO 129                                      STAT  56
      DO 109 K=LOCHN,NHICHN                                          STAT  57
  109 RES(I)=RES(I)+(AT(K,L)*AT(K,J)*RHO(K)*R(I,N)*R(I,M)/(A(K)**2))  STAT  58
      N=N+1                                                          STAT  59
      IF(N.GT.NISO)GO TO 130                                        STAT  60
  129 CONTINUE                                                       STAT  61
  130 M=M+1                                                          STAT  62
      IF(M.GT.NISO)GO TO 131                                        STAT  63
  119 CONTINUE                                                       STAT  64
  131 CONTINUE                                                       STAT  65
      DO 112 I=1,NISO                                                STAT  66
      RES(I)=SQRT(RES(I)+S2(I))*C(I)                                 STAT  67
  112 ST(I)=BETA(I)/RES(I)                                           STAT  68
      GO TO 105                                                      STAT  69
  100 DO 501 I=1,NISO                                                STAT  70
      IF(R(I,I).GE.0.)GO TO 503                                      STAT  71
      WRITE(6,28)O(I)                                                STAT  72
      R(I,I)=ABS(R(I,I))                                             STAT  73
  503 RES(I)=SQRT(R(I,I)*VAREST+S2(I))*C(I)                          STAT  74
  501 ST(I)=BETA(I)/(RES(I))                                         STAT  75
  105 F=(REMOVE/FLOAT(NISO))/VAREST                                  STAT  76
      RETURN                                                         STAT  77
      END                                                            STAT  78
      SUBROUTINE INIT(NITER,RAT,SAV,C,ISOCHN,MODE,NBKGD,NUBKG,NSHFT,NPK, INIT  1
     1LPP,NORM,NCTIN,NAREA,NCHCU,NCULL,NCUUL,NRHO,NUMVAR,NVAR,NREFS,ITER INIT  2
     2,NR,NW,LOCHN,NHICHN,NCHAN,MC,MVAR,T,AREA,BKGTIM,TIMIRR,FRHL,UP,    INIT  3
     3XNCOM)                                                            INIT  4
      DIMENSION C(15)                                                   INIT  5
      NITER=0                                                           INIT  6
      RAT=1.0                                                           INIT  7
      SAV=0.0                                                           INIT  8
      DO 15  I=1,15                                                     INIT  9
   15 C(I)=1.0                                                          INIT 10
      ISOCHN=256                                                        INIT 11
      MODE=2                                                            INIT 12
      NBKGD=1                                                           INIT 13
      NUBKG=1                                                           INIT 14
      NSHFT=1                                                           INIT 15
      NPK=3                                                             INIT 16
      LPP=1                                                             INIT 17
      NORM=1                                                            INIT 18
      NCTIN=1                                                           INIT 19
      NAREA=1                                                           INIT 20
      NCHCU=48                                                          INIT 21
      NCULL=33                                                          INIT 22
      NCUUL=40                                                          INIT 23
      NRHO=1                                                            INIT 24
      NUMVAR=1                                                          INIT 25
      NVAR=3                                                            INIT 26
      NREFS=0                                                           INIT 27
      ITER=0                                                            INIT 28
      NR=0                                                              INIT 29
      NW=1                                                              INIT 30
      LOCHN=7                                                           INIT 31
      NHICHN=250                                                        INIT 32
      NCHAN=256                                                         INIT 33
      MC=1                                                              INIT 34
      MVAR=0                                                            INIT 35
      T=1.645                                                           INIT 36
      BKGTIM=60.0                                                       INIT 37
      TIMIRR=15.0                                                       INIT 38
      FRHL=774.0                                                        INIT 39
      UP=2.5758                                                         INIT 40
      XNCOM=1.0                                                         INIT 41
      RETURN                                                           INIT 42
      END                                                              INIT 43
N
```

APPENDIX   J

-FLOW DIAGRAM OF THE CODE

CORGAM- Main and Subroutines
calling diagram

Flowchart:

START
↓
READ A CONTROL CARD FOR THE DATA SET
↓
NCHAN — E → EXIT
↓
READ Y DATA SET
↓
NBKGD — E → (branch)
↓
CORRECT Y FOR BACKGROUND
↓
CALCULATE IRRAD. TIME CORRECTION
↓
NORM — S → (branch)
↓
NORMALIZE Y
↓
(branches)
- USE PREVIOUS VAR. SPECTRUM
- READ AND AVERAGE NUMVAR VARIANCE SPECTRUM
- SET VARIANCE SPECTRUM = 1
- SET VARIANCE SPECTRUM = Y
↓
READ REF. SPEC. CONTROL CARD
↓
NORF:1 — E → READ A REF. SPECTRUM DATA SET
↓
READ A REFERENCE SPECTRUM
↓
NREF — E → (branch)
↓
SHIFT REF. SPECTRUM
↓
CALCULATE DECAY CORRECTION
↓ D

CORRECT FOR BACKG. & NORMALIZE REF. SPEC.

Right column:

C → / ALL REF. SPEC. READ — No / Yes
NFORM=1: READ (K'WK)⁻¹
NFORM=2: FORM (K'WK)⁻¹
↓
CALCULATE MEAN FOR Y
↓
CALCULATE AVERAGE RATIO OF Y TO VARIANCE SPECTRUM
↓
CALCULATE L.S. ESTIMATORS
↓
DELETE REFERENCE SPECTRA ACCORDING TO INPUT DATA
↓
CALCULATE STD. DEVIATIONS AND T VALUES FOR L.S. ESTIM.
↓
ITER — S → (branch)
↓
CALCULATE QUALITY OF FIT
↓
Q.F. WITHIN RANGE ? — Yes → / No
↓
CORRECT VARIANCE SPECTRUM
↓
ANY REF. SPECT. T SIGNIF ? — No / Yes
↓
DELETE THE ONE WITH THE SMALLEST T VALUE
↓
CALCULATE QUALITY OF FIT, TOTAL ABSOLUTE DEVIATIONS, FITTED COMPLEX SPECTRUM
↓
DATA SET COMPLETE ? — No → A / Yes → START

APPENDIX   K

- LISTING OF THE INPUT DATA FOR SAMPLE PROBLEM

The following is the listing of the input data cards used for the analysis of the sample problem data.They are listed in order of appearence in the program.For further use change of some of the control cards is sufficient.The data can be read from punched cards as well as from a storage file or from a magnetic tape.The listing of the input data is also given together with the read formats.The options are given in the comments cards of CORGAM and in the appendix F.

1.Card:(15A4) ID card for the complex spectraum
2.Card:(25I3)

   NISO:Number of isotopes in complex spectra used in the analysis

   NCASES:Number of complex spectra to be analyzed

   NRES:Resonance calculation control parameter (optional)

   NFORM:Least-squares fit control parameter (optional)

   NWRIT:(X'WX) matrix writing control parameter (optional)

   NCORR:Correlation coefficient control parameter (optional)

   NINTF:Interferences calculation control parameter (optional)

   NIDEN:Identity matrix control parameter (optional)

3.Card:(25I3)

   NCHG1:Change in NAM1 (optional)

   NCHG2:Change in NAM2 (optional)

   NCHG3:Change in NAM3 (optional)

 (NAM1,NAM2,NAM3 are the NAMELIST variables)

4.Card:If change in NAM1 is required,new values are given by this card

5.Card: "   NAM2   "   "   "

6.Card: "   NAM3   "   "   "

7.Card: "   "   "   "   "

   NAM1 contains ISOCHN,MODE,NBKGD,NUBKG,NSHFT,NPK,LPP,NORM,NCTIN
   NHICHN,NCHAN,MC,MVAR

   NAM2 contains C(I)

   NAM3 contains T,DECAY,COUNT,WT,CUCT,WTCU,AREA,CUDEC,BKGTIM,TIMIRR,
   FRHL,UP,XNCOM

   The definitions of these variables are given in the comments of

CORGAM.These variables are entered in the program by a DATA statement,if a change is required,this is done in the 3.card and the new values are given in 4.,5.,6. and 7. cards.If a specific isotope wont be used in the analysis -1.0 will be entered in NAM2 for the C(I) value of the Ith isotope.For the complex spectra following the first one (if any) ,the input parameters are read from the subprogram INIT.

8.Card:(15A4) Complex spectrum ID card

9.Card up to 30.Card (included) (6X,12(F6.0,2X)) :

This is the complex spectrum data set.The variable name is RHO(I) where I is from 1 to ISOCHN.ISOCHN is the number of the channel contained in the complex spectrum.Maximum value of I can be 400,and 12 values are punched on each card.If the channel numbers are less than 400 (as in the case of sample problem 256),only the values prespecified are read.

31.Card:(15A4) Background ID card

32.Card up to 53.Card (included) (6X,12(F6.0,2X)):Background spectrum deck,

The variable name is BKG(I) where I is from 1 to ISOCHN

54.Card: Flux reference spectrum ID card

55.Card up to 58.Card (included) (6X,12(F6.0,2X)): Flux reference spectrum data set.The variable name is RES(I) where I is from 1 to NCHCU.

NCHCU is the channel number contained in the flux reference spectrum.

59.Card:(8F10.0) The gain of the system in MeV/ch.The variable name is GAİN

60.Card:(4(I3,7X,F10.0)) IXO(I),E(I) I from 1 to NPK,where the variable

IXO is the approximate mid-point of photopeak,E is the energy of the gamma photopeak in MeV.Both values are for the complex spectrum.NPK being the number of the photopeaks in the complex spectrum.

61.Card:(A4,9I3) O(I),ISO(I),NPK,LPP,NORF,MODE,NFAC(I),NO

O(I):Tag name of the Ith isotope

ISO(I):Number of channels in the Ith reference isotope

NPK:is the photo-peaks contained in the complex spectrum

LPP:Index of photo-peak used in shifting

NORF:Specification for normalization of reference spectra

MODE:Reference spectrum input specification

NFAC(I):Decay time specification of reference spectrum

NO:Number of decay spectra of a specific reference isotope

62.Card:(8F10.0) H(I),D(I),FRRHL,XNORM(I)

H(I): Half-life,in minutes,of reference isotope spectrum

D(I): Irradiation time,in minutes,of reference sample spectrum

FRRHL:Reference spectrum,flux reference isotope half-life,in minutes

XNORM(I):Normalization constant of the Ith reference isotope

63. and 64. Cards: (8F10.0) T(J),C(J) J from 1 to NO

These data are for the reference decay spectra. Where T(J) is the decay time in minutes of the Jth decay spectra and C(J) is the count time in minutes of the Jth decay spectra. NO being the number of the decay spectra.

65. Card: (25I3) NUBKG,NCULL,NCUUL,NCHCU,NCHBK

NUBKG: Background spectra specification

NCULL: Lower fit limit on copper reference photopeak

NCUUL: Upper   "   "   "   "   "

NCHCU: Number of channels in copper reference spectrum

NCHBK: Number of channels in background spectrum

66. Card: (8F10.0) COUN,DECA,BKGTIM,CUDEC,WT,WTCU,CUCT

COUN: Counting time, in minutes, for reference spectrum

DECA: Decay time, in minutes, for reference spectrum

BKGTIM: Background counting time, in minutes, for reference spectrum

CUDEC: Decay time, in minutes, for flux reference spectrum

WT: Weight, in grams, of the reference isotope

WTCU: Weight, in grams, of the flux reference isotope

CUCT: Counting time, in minutes, for the reference spectrum, flux referenc spectrum.

67. Card up to 186. Card (5E14.8) CT(J,M) J from 1 to ISOCHN, M from 1 to NO

These are the decay spectra of the reference isotopes, where CT(J,M) is the counts registered at Jth channel of the reference isotope Mth decay time. NO is the number of decay spectra. If an isotope doesn't have a decay spectra M is assumed to be equal to 1.

187. Card: same as card 61

188. Card: same as card 62

189. and 190. Cards: same as cards 63 and 64

191. Card: same as card 65

192. Card: same as card 66

193. Card and the following deck: same as 67. card and the following deck. The same order repeats itself till all the reference isotopes are read in. In the sample problem data this repetition ends at the 458. card. From this point on the next complex spectrum data is given, using the same formats as in the first spectrum.

459. Card: same as card 3

460. Card: same as card 4

461. Card: same as card 5

462. Card: same as card 6

463.Card:same as card 7
464.Card:same as card 8
465.Card up to 486.Card:same as the 9. card up to 30. card

The same order repeats itself till all the complex spectra are read in.

```
S J CHEN
10  4  2  3  0  0  0  0
   1  1      1
&NAM1 NHICHN=204,NRHO=0,&END
&NAM2 C(3)==1,0,C(4)==1,0,C(6)==-1,0,&END
&NAM3 DECAY=82,0,33,COUNT=10,,WT=0,0362,CUCT=2,0,
WTCU=0,0338,CUDEC=1058,584,&END
5  5    37,      3,    227,    382,   1504,   4630,   2331,   1400,   1270,   1090,    931,    929,    1
5  5   954,    952,    990,   1097,   1114,   1005,    898,    860,    840,    835,    830,    842,    2
5  5   746,    808,    693,    662,    701,    673,    645,    614,    638,    721,    698,    723,    3
5  5   713,    614,    730,    664,    684,    535,    375,    349,    286,    255,    211,    211,    4
5  5   229,    201,    349,    664,   1465,   2464,   3256,   3083,   1903,   1025,    448,    128,    5
5  5   129,    133,    136,    130,    128,    146,    158,    149,    157,    153,    134,    128,    6
5  5   110,    137,    155,    122,    161,    144,    147,    135,    154,    153,    135,    162,    7
5  5   173,    152,    145,    137,    148,    136,    147,    157,    139,    180,    212,    227,    8
5  5   174,    195,    183,    164,    133,    152,    153,    165,    132,    120,    120,    129,    9
5  5   120,    146,    156,    204,    258,    295,    304,    331,    249,    204,    147,     90,   10
5  5    67,     44,     38,     28,     22,     24,     26,     32,     86,     49,     75,    109,   11
5  5   143,    183,    170,    165,    142,    117,    115,     82,     66,     45,     35,     17,   12
5  5    11,     14,      7,     12,      9,     10,      7,      8,     10,      9,     12,     10,   13
5  5     8,     10,     12,      7,      6,      6,     12,     10,      4,     12,     10,     11,   14
5  5     0,     12,      5,     11,      2,      6,      2,      7,      1,      3,      5,      3,   15
5  5     3,      2,      1,      3,      2,      2,      2,      1,      2,      3,      4,      2,   16
5  5     2,      3,      2,      5,      3,      0,      1,      1,      0,      1,      2,      3,   17
5  5     0,      1,      1,      1,      0,      0,      2,      2,      0,      1,      0,      1,   18
5  5     0,      1,      1,      1,      1,      1,      0,      1,      0,      0,      0,      0,   19
5  5     1,      1,      1,      0,      0,      0,      0,      2,      2,      0,      1,      0,   20
5  5     2,      1,      1,      1,      1,      1,      0,      2,      2,      0,      0,      0,   21
5  5     0,      5,      3,      3,      1,      1,                                                  22
1  1   145,     10,   1315,   2110,   5204,  11201,   5405,   2324,   1781,   1080,    823,    714,    1
1  1   772,    696,    798,    719,    715,    735,    652,    647,    557,    536,    514,    481,    2
1  1   476,    467,    400,    355,    357,    329,    309,    339,    329,    378,    372,    335,    3
1  1   280,    264,    274,    272,    269,    250,    213,    210,    199,    174,    183,    188,    4
1  1   191,    185,    180,    188,    147,    178,    172,    158,    142,    157,    167,    171,    5
1  1   150,    140,    118,    142,    119,    115,    113,    128,     93,    111,    106,    109,    6
1  1   123,     99,    112,    114,     85,    102,     73,     81,     81,     60,     64,     64,    7
1  1    69,     80,     75,     75,     85,     91,     92,    116,    100,    136,     95,     51,    8
1  1    79,     44,     55,     30,     39,     41,     25,     37,     37,     33,    107,     95,    9
1  1    30,     37,     37,     34,     33,     42,     35,     17,     22,     33,     39,     26,   10
1  1    29,     24,     19,     20,     24,     19,     17,     17,     15,     24,     22,     22,   11
1  1    12,     21,     26,     25,     25,     26,     19,     19,     22,     15,     18,     13,   12
1  1    15,     12,     13,     13,     14,     20,     16,     16,     22,     17,     19,     26,   13
1  1    10,     17,     13,     16,     10,     11,      6,      7,     14,     11,     11,     11,   14
1  1     7,      8,      6,     10,     10,      9,      7,     11,      7,      8,      7,      6,   15
1  1     6,     10,     10,      8,      4,      4,      6,      5,      7,      8,      6,     13,   16
1  1     6,      8,      8,      8,      4,      4,      7,      6,      7,      6,      7,      8,   17
1  1     5,      4,      4,      4,      3,      6,      5,      5,      4,      4,      6,      5,   18
1  1     9,      8,      9,      5,      5,      5,      3,      5,      4,      3,      4,      4,   19
1  1     6,      6,      4,      9,      4,                   10,                   3,            3,   20
1  1     3,      6,      4,      4,                                                                  21
                                                                                                   22
CHEN CU REE
        1   5590  10056   6002   7501   7429   7323   7320   7557   7383   6471   4822
     3594  2921   2705   2427   2461   2400   2804   5929  18981  42037  53059  35133
    11843  2296    417    195    152    146    130    160    164    156    146    139
0,0145
           0,845       115          1,81       135          2,12
R=1115   1   1    0    1    1
      1,000    2,0    15,0    774,000    5,0    0,007
5,0          2,0      31,0       5,0      62,0      5,0         145,0      10,0
```

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CL3816
37.3

MN56192   2   1   0   2   0

MG27139   2   1   0   2   0   0
9.5

&NAM1 NJBKG=0,NAREA=2,NREFS=0,NHICHN=204,VRHO=0,&END
&NAM2 C(3)=1.0,C(4)=-1.0,C(6)=-1.0,C(10)=-1.0,&END
&NAM3 DECAY=126.5833,COUNT=10.,WT=0.0386,CHCT=2.0,
WTCU=0.0338,CUDEC=1058.584,&END

```
 8  8    95.   137.   172.   193.   257.   295.   363.   31?.   257.   187.   136.    90. 10
 8  8    50.    46.    35.    30.    25.    25.    21.    33.    54.    41.    63.    01. 11
 8  8   120.   145.   133.   145.   104.    90.    21.    51.    31.    25.    18.    15. 12
 8  8    1?.    15.    1?.     7.    11.     5.     7.    11.    63.    12.     8.    10. 13
 8  8     7.    10.    15.    19.     9.    15.     9.    12.     .     12.     8.    10. 14
 8  8     3.    11.    10.    14.     8.     7.     8.     5.     3.     7.     5.     5. 15
 8  8     .      4.     .      4.     1.     5.     2.     .      3.     4.     .      1. 16
 8  8     2.     0.     3.     2.     1.     4.     1.     5.     3.     1.     0.     1. 17
 8  8     1.     2.     .      2.     0.     2.     1.     .      3.     1.     1.     0. 18
 8  8     2.     2.     6.     2.     0.     2.     2.     2.     .      .      3.     1. 19
 8  8     1.     0.     0.     1.     1.     1.     1.     1.     .      1.     0.     0. 20
 8  8     0.     3.     2.     2.     .      0.     0.     2.     .      .      3.     1. 21
 8  8     .      3.     0.     0.                                                       22
```

```
0.0145      0.845      115        1.81       135        2.12
35 45 58 70 72 88 90 94 102 105 113 123 125 146 149 189 214 219
1   1   1
&NAM1 NUBKG=0,NAREA=2,NREFS=0,NHICHN=204,NRHO=0,&END
&NAM2 C(3)=-1.0,C(4)=-1.0,C(6)=-1.0,C(10)=-1.0,&END
&NAM3 DECAY=138.5833,COUNT=10.,WT=0.0331,CHCT=2.0,
WTCU=0.0338,CUDEC=1058.584,&END
```

```
 9  9    41.     2.   188.   366.  1649.  4991.  2130.  1159.   952.   802.   673.   690.  1
 9  9   540.   615.   668.   754.   787.   730.   650.   580.   587.   630.   595.   565.  2
 9  9   513.   501.   490.   487.   492.   467.   445.   425.   442.   486.   466.   482.  3
 9  9   478.   482.   488.   450.   429.   337.   284.   226.   194.   177.   157.   148.  4
 9  9   170.   190.   244.   447.   891.  1620.  2159.  2047.  1324.   646.   278.   131.  5
 9  9   115.    91.   103.    83.    92.    87.    88.   105.   105.   102.    90.    80.  6
 9  9   104.   107.   109.   104.   112.    92.    88.   109.    73.   136.   145.   143.  7
 9  9    87.   103.    93.    80.   101.   113.    94.   109.    73.   136.   145.   143.  8
 9  9   156.   145.   133.   112.    93.    88.    87.    76.    85.    89.    51.    44.  9
 9  9    52.    74.   100.   125.   175.   210.   215.   210.   167.   136.   103.    67. 10
 9  9    40.    26.    23.    21.    17.    10.    23.    31.    44.    55.    73. 11
 9  9    77.   119.    93.    78.    97.    61.    59.    34.    28.    12.    18.     2. 12
 9  9    14.    11.     9.     5.     8.     8.     5.     5.    10.     7.     2. 13
 9  9    11.     3.    11.     9.     6.     7.     9.    12.     5.     7.     2. 14
 9  9     6.    14.     9.     7.     5.     6.     7.     6.     5.     7.     3.     6. 15
 9  9     3.     4.     1.     2.     2.     3.     2.     1.     3.     1.     .      1. 16
 9  9     2.     4.     2.     2.     0.     0.     2.     2.     1.     0.     3.     3. 17
 9  9     0.     2.     3.     .      1.     2.     2.     3.     1.     1.     1.     0. 18
 9  9     1.    12.     1.     0.     1.     0.     0.     1.     .      .      1.     0. 19
 9  9     2.     1.     2.     2.     1.     1.     0.     2.     1.     2.     1. 20
 9  9     1.     1.     2.     0.                                                     22
```

```
0.0145      0.845      115        1.81       135        2.12
35 45 58 70 72 88 90 94 102 105 113 123 125 146 149 189 214 219
1   1   1
&NAM1 NUBKG=0,NAREA=2,NREFS=0,NHICHN=204,NRHO=0,&END
&NAM2 C(3)=-1.0,C(4)=-1.0,&END
&NAM3 DECAY=58.5840,COUNT=10.,WT=0.0347,CUCT=2.0,
WTCU=0.0338,CUDEC=1058.584,&END
```

```
 3  3    31.     5.   215.   373.   831.  2656.  1790.  1427.  1213.  1019.  1003.   932.  1
 3  3   898.   881.   932.  1033.  1025.   955.   876.   761.   771.   756.   756.   708.  2
 3  3   678.   663.   675.   612.   629.   612.   604.   643.   628.   686.   724.   641.  3
 3  3   536.   637.   578.   607.   550.   468.   425.   325.   271.   240.   246.   253.  4
 3  3   251.   229.   336.   586.  1207.  2247.  2811.  2622.  1747.   930.   359.   207.  5
 3  3   144.   129.   126.   128.   138.   143.   145.   145.   153.   146.   146.   149.  6
 3  3   150.   160.   147.   152.   152.   142.   151.   145.   166.   153.   175.   225.  7
 3  3   183.   129.   166.   152.   137.   129.   155.   160.   162.   182.   224.   245.  8
 3  3   195.   197.   174.   168.   160.   185.   190.   175.   166.   187.   148.    98.  9
 3  3   123.   121.   135.   191.   235.   306.   289.   255.   166.   136.   120. 10
 3  3    58.    38.    28.    25.    32.    27.    31.    28.    72.    90.    19. 11
 3  3   138.   183.   168.   175.   168.   153.   111.    90.    55.    35.    19. 12
 3  3    10.    12.    14.     7.     8.     3.    10.     .      .      .     10. 13
 3  3    11.    13.    17.    14.     7.    11.     5.     .      .     10.     5. 14
 3  3    4.      3.      3.      5.      3.      2.      3.      .      3.      3.      5. 15
 3  3    2.      3.      1.      1.      1.      0.      2.      2.      1.      1.      1. 16
 3  3    2.      3.      2.      0.      1.      2.      2.      .      .      1.      1. 17
 3  3    1.      0.      1.      0.      4.      0.      1.      0.      .      .      1. 18
 3  3    2.      0.      1.      2.      2.      3.      2.      2.      .      .      0. 19
 3  3    0.      1.      2.      0.                                                   20
 3  3    0.      1.      0.      0.                                                   22
```

```
0.0145      0.845      115        1.81       135        2.12
35 45 58 70 72 88 90 94 102 105 113 123 125 146 149 189 214 219
```

```
E                XO                      BO                    YO                    AREA
 .845    +OR-  55.249         +OR-   6.337       +OR-  .13692+004     .61093+004
               .136                  .188              .15361+003  +OR- .74122+003

E                XO                      BO                    YO                    AREA
1.810    +OR- 115.042         +OR-  19.692       +OR-  .13263+003     .10432+00"
               .940                 4.248              .33023+002  +OR- .30457+003

E                XO                      BO                    YO                    AREA
2.120    +OR- 135.013         +OR-  19.188       +OR-  .73560+002     .57112+003
              1.237                 5.442              .24698+002  +OR- .22336+003

OLD GAIN =      .1602032-001 INTERCEPT =  -.3869112-001
BASE LINE SHFT =   .2415128+001 NEW GAIN =     .1450000-001 RATIO =    .1103076+001

E                XO                      BO                    YO                    AREA
 .845    +OR-  58.322         +OR-   8.198       +OR-  .12147+004     .61645+004
               .127                  .205              .11347+003  +OR- .56612+003

E                XO                      BO                    YO                    AREA
 .810    +OR- 124.247         +OR-  24.105       +OR-  .12001+003     .10444+004
               .801                 3.750              .24175+002  +OR- .23970+003

E                XO                      BO                    YO                    AREA
 .120    +OR- 146.452         +OR-  33.923       +OR-  .63684+002     .66053+003
              1.518                 9.525              .18211+002  +OR- .22922+003
```

NON SHIFTED SPECT

SHIFTED SPECT

FACTORS = Y

BR-1

DECAY AND IRR CORRECTION FACTORS

BR-1 =   .10000+007   CU64 =   .10811+007   AL28 = -.46373+018   S370 = -.21675+012   NA24 =   .10684+007   CA49 = -.1455...

...   .10847+007   CL38 =   .55351+007   MN56 =   .15113+007   MG27 =   .85569+009

COMPLEX SPECT

.2417303+003   .2337888+003   .2233334+003   .2155001+003   .2298346+003
.2586095+003   .2451725+003   .2568013+003   .2589026+003   .2209527+003
.2057753+003   .2553551+003   .2440520+003   .2237091+003   .1732545+003
.1476300+003   .1189855+003   .9780139+002   .8022201+002   .1018411+003
.1574380+003   .3105883+003   .6198850+002   .9642585+003   .1243602+004
.1201258+004   .8021252+003   .4696740+003   .2306045+003   .1007806+003
.3704309+002   .4285724+002   .4464856+002   .4088555+002   .4155086+002
.4611520+002   .5305611+002   .5028908+002   .4588817+002   .5082248+002
.5042586+002   .4355166+002   .4105088+002   .5034053+002   .5164980+002
.5054759+002   .4808097+002   .5367096+002   .4806953+002   .4824342+002
.5508106+002   .6239125+002   .5454210+002   .5177809+002   .5074710+002
.5098499+002   .5041302+002   .4698333+002   .5150015+002   .6484710+002
.5895138+002   .6042941+002   .7355499+002   .8214603+002   .4864949+002
.6064254+002   .6916320+002   .6470442+002   .5795908+002   .4954785+002
.5004244+002   .5726421+002   .6127045+002   .5215975+002   .5560095+002
.4460310+002   .4586386+002   .4606084+002   .4674495+002   .1137215+003
.6041255+002   .7858974+002   .9772905+002   .1102209+003   .4703966+002
.1268004+003   .1041220+003   .8529286+002   .6735072+002   .5265241+002
.2919040+002   .1936967+002   .2924662+002   .4100570+002   .4803237+002
.6609962+002   .6453635+002   .6321636+002   .5684723+002   .1557878+002
.4419027+002   .3904920+002   .2089529+002   .2412620+002   .1808243+001
.1477158+001   .3481919+001   .1087159+001   .6187957+001   .1559693+001
.1056081+001   .1200479+001   .1557701+001   .1599089+001   .1559693+001
.2592990+001

CORRELATION COEFF

10   .10000+001   .40156+000   .38150-001   .48931-002   .11788-001   .79557-002   .5984-001   .44798-001   .26192+000   .20509+000
.40156+000   .10000+001   .10468-001   .19419-002   .33833-002   .35869-002   .16198-001   .1342-001   .1000-000   .64841-001
.38150-001   .10468-001   .10000+001   .16974-001   .75964-001   .26967-001   .22032+000   .34082-000   .25722-001   .86553-001
.48931-002   .19419-002   .16974-001   .10000+001   .71461+000   .98677+000   .11588-000   .62942-001   .53565-001   .72644-002
.11788-001   .33833-002   .75964-001   .71461+000   .10000+001   .76408+000   .30123-001   .55468-001   .14467+000   .29294-001
.79557-002   .35869-002   .26967-001   .98677+000   .76408+000   .10000+001   .18320-001   .16131+000   .14467+000   .11636-001
.5984-001   .16198-001   .22032+000   .11588-001   .30123-001   .18320-001   .10000+001   .10000+001   .21136+000   .92832-001
.44798-001   .1342-001   .34082-000   .62942-001   .55468-001   .16131+000   .10000+001   .10000+001   .10000+001   .50305+000
.26192+000   .1000-000   .25722-001   .27293-001   .55365-001   .39050-001   .14447+000   .10000+001   .10000+001   .50305+000
.20509+000   .64841-001   .86553-001   .72644-002   .29294-001   .11636-001   .11853+000   .92832-001   .50305+000   .10000+001

FF(IN PER CENT) =   .40960344997+000

CROSS PRODUCT MATRIX

INV CROSS PRODUCT MATRIX

INV ERROR =   .1109123-004

IDENTITY MATRIX

INTERFERENCES IN PER CENT

BR-1 CU64 .33129+002 AL28 .34080+000 S370 .58110-002 NA24 .42128-001 CA49 .12584-001 K420 .30729+000 CL38 .52735-003 MN56 .50116+001 MG27 .16896+001

CU64 AL28 .98781-002 S370 .55387+000 NA24 .27170+000 CA49 .61238+000 K420 .95915-002 CL38 .14668+000 MN56 .68628-001 MG27 .19022+000

AL28 S370 .41628+000 NA24 .59045+001 CA49 .10878+001 K420 .78202+001 CL38 .98716+001 MN56 .11703+002 MG27 .27300+001

S370 NA24 .16899+002 CA49 .98725+002 K420 .21513+000 CL38 .12289+002 MN56 .69020+000 MG27 .32810+000

NA24 CA49 .30084+002 K420 .16608+000 CL38 .34992+001 MN56 .13488+001 MG27 .21339+001

CA49 K420 .26257+000 CL38 .13208+002 MN56 .10819+001 MG27 .66054+000

K420 CL38 .26989+001 MN56 .12830+000 MG27 .25414+001

CL38 MN56 .14538+001 MG27 .11412-001

MN56 MG27 .35122+002

(ATRANS * OMEGA * R40)

10 .31905+007 .24420+007 .19313+009 .28651+005 .63610+007 .28482+005 .51989+005 .57712+007 .17032+009 .15614+007

ISOTOPE REMOVED AL28

ISOTOPE REMOVED S370

ISOTOPE REMOVED CA49

ITERATION, 0 OF 0 MAX ITER

	BR-1	CU64	NA24	K420	CL38	MN56	MG27
SOL(PPM)	.1256+003	-.6845+002	.9456+001	.2840+005	.2755+004	.2571+003	.5669+005
STD DEV	.8029+002	.5875+002	.8508+001	.2308+004	.1322+003	.3382+001	.1245+006
T VALUES	.1565+001	-.1131+001	.1112+001	.1231+002	.2086+002	.7601+002	.4549+000

F VALUE = .1647+002 CORR COEF = .9936+000

ISOTOPE REMOVED CU64

ITERATION, 0 OF 0 MAX ITER

	BR-1	NA24	K420	CL38	MN56	MG27
SOL(PPM)	.7461+002	.9575+001	.2845+005	.2759+004	.2569+003	.5669+005
STD DEV	.5330+002	.8508+001	.2305+004	.1321+003	.3394+001	.1245+006
T VALUES	.1400+001	.1125+001	.1234+002	.2089+002	.7570+002	.4554+000

F VALUE = .1921+002 CORR COEF = .9934+000

ISOTOPE REMOVED MG27

ITERATION, 0 OF 0 MAX ITER

	BR-1	NA24	K420	CL38	MN56
SOL(PPM)	.7762+002	.1109+002	.2864+005	.2760+004	.2578+003
STD DEV	.5268+002	.8176+001	.2283+004	.1322+003	.2582+001
T VALUES	.1474+001	.1357+001	.1255+002	.2086+002	.9986+002

F VALUE = .2305+002 CORR COEF = .9934+000

ISOTOPE REMOVED NA24

ITERATION, 0 OF 0 MAX ITER

	BR-1	K420	CL38	MN56
SOL(PPM)	.7980+002	.2898+005	.2788+004	.2578+003
STD DEV	.5260+002	.2269+004	.1306+003	.2581+001
T VALUES	.1517+001	.1276+002	.2134+002	.9986+002

F VALUE = .2881+002 CORR COEF = .9934+000

ISOTOPE REMOVED BR-1

ITERATION, 0 OF 0 MAX ITER

	K420	CL38	MN56
SOL(PPM)	.2932+005	.2780+004	.2578+003
STD DEV	.2255+004	.1305+003	.2317+001
T VALUES	.1300+002	.2130+002	.1113+003

F VALUE = .3841+002 CORR COEF = .9932+000

DEG OF FREEDOM = 112. QUAL OF FIT = .204+001

ABS DEV PER PT = .7490734+001 NO OF PTS = 116

CHN	EXP	CALC	RES	CHN	EXP	CALC	RES

T VALUE =   1.6450

SAMPLE WT(GM) = .3960n-001 IRR TIME(MIN) = .15000+002 DECAY TIME(MIN) = .12656+003 COUNT TIME = .10000+002
FLUX REF WT(GM) = .33800-001 REF DECAY TIME(MIN) = .10556+004 REF COUNT TIME(MIN) = .20000+001 REF HLIFE(MIN) = .1770u+10
BKG TIME(MIN) = .6000n+002

Y NORM CONSTANT = .25n88707+001

E
.845   +OR- $X0$ 55.292   +OR- $B0$ 6.082   +OR- $Y0$ .14090+004   +OR- AREA .56959+004
              .138   .182   .16611+003   .73599+003

E
1.810   +OR- $X0$ 115.015   +OR- $B0$ 14.829   +OR- $Y0$ .13337+003   +OR- AREA .91004+003
              .733   2.503   .34285+002   .25766+003

E
2.120   +OR- $X0$ 134.848   +OR- $B0$ 18.353   +OR- $Y0$ .55061+002   +OR- AREA .42569+003
              1.326   5.758   .20351+002   .18110+003

OLD GAIN = .1605694-001 INTERCEPT = -.4161721-001
BASE LINE SHFT = .2591852+001 NEW GAIN = .1450000-001 RATIO = .1105872+001

E
.845   +OR- $X0$ 58.312   +OR- $B0$ 7.691   +OR- $Y0$ .14605+004   +OR- AREA .57041+004
              .126   .193   .11402+003   .56950+003

E
1.810   +OR- $X0$ 124.372   +OR- $B0$ 19.695   +OR- $Y0$ .11896+003   +OR- AREA .93571+003
              .695   2.609   .26040+002   .22279+003

E
2.120   +OR- $X0$ 146.336   +OR- $B0$ 23.668   +OR- $Y0$ .58180+002   +OR- AREA .45862+003
              1.328   6.476   .18070+002   .18919+003

NON SHIFTED SPECT

SHIFTED SPECT

WT FACTORS = Y

BR-1

DECAY AND IRR CORRECTION FACTORS

COMPLEX SPECT

CORRELATION COEFF

EFF(IN PER CENT) =   .703176088631+000

CROSS PRODUCT MATRIX

INV CROSS PRODUCT MATRIX

INV ERROR =   .5339384-005

IDENTITY MATRIX

INTERFERENCES IN PER CENT:

	CU64	AL28	S370	NA24	CA49	K420	CL38	MN56	MG27
BR-1	.31393+002	.33863+000	.71615-002	.55203-001	.15209-001	.29233+000	.77502-002	.54066+001	.16927+001
CU64	.96617-002 (AL28)	.50425+000 (S370)	.21223+000 (NA24)	.54822+000 (CA49)	.50307-002 (K420)	.16948+000 (CL38)	.74224-001 (MN56)	.18237+000 (MG27)	
AL28	.47196+000 (S370)	.83964+001 (NA24)	.12023+001 (CA49)	.85460+001 (K420)	.85028+001 (CL38)	.11327+002 (MN56)	.23385+001 (MG27)		
S370	.14227+002 (NA24)	.98769+002 (CA49)	.11551+000 (K420)	.16785+002 (CL38)	.62462+000 (MN56)	.27654+000 (MG27)			
NA24	.25855+002 (CA49)	.76683-001 (K420)	.48933+001 (CL38)	.12103+001 (MN56)	.22090+001 (MG27)				
CA49	.14319+000 (K420)	.18468+002 (CL38)	.99180+000 (MN56)	.58122+000 (MG27)					
K420	.20343+001 (CL38)	.97560-001 (MN56)	.26394+001 (MG27)						
CL38	.16975+001 (MN56)	.57820-003 (MG27)							
MN56	.33427+002 (MG27)								

(ATRANS * OMEGA * RHO)

| 10 | .34021+007 | .26039+007 | .20593+009 | .30551+005 | .67827+007 | .30370+006 | .55436+005 | .61539+007 | .18161+009 | .16649+007 |

ISOTOPE REMOVED AL28

ISOTOPE REMOVED S370

ISOTOPE REMOVED CA49

ISOTOPE REMOVED MG27

ITERATION, 0 OF 0 MAX ITER

	BR-1	CU64	NA24	K420	CL38	MN56
SOL(PPM)	.9589+002	.3198+002	.3208+002	.2908+005	.3088+004	.2973+003
STD DEV	.7256+002	.5756+002	.8845+001	.2431+004	.2528+003	.2929+001
T VALUES	.1321+001	.5556+000	.3625+001	.1352+002	.1212+002	.1015+003

F VALUE = .1921+002 CORR COEF = .9933+000

ISOTOPE REMOVED CU64

ITERATION, 0 OF 0 MAX ITER

	BR-1	NA24	K420	CL38	MN56
SOL(PPM)	.1181+003	.3188+002	.2904+005	.3060+004	.2973+003
STD DEV	.4944+002	.8835+001	.2148+004	.2528+003	.2929+001
T VALUES	.2388+001	.3609+001	.1352+002	.1210+002	.1015+003

F VALUE = .2305+002 CORR COEF = .9933+000
DEG OF FREEDOM = 110. QUAL OF FIT = .201+001
ABS DEV PER PT = .6427585+001 NO OF PTS = 116

S
SAMPLE WT(GM) = .33100-001 IRR TIME(MIN) = .15000+002 DECAY TIME(MIN) = .13856+003 COUNT TIME = .10000+002
FLUX REF WT(GM) = .33800-001 REF DECAY TIME(MIN) = .10586+004 REF COUNT TIME(MIN) = .20000+001 REF HLIFE(MIN)
BKG TIME(MIN) = .6000+002

Y NORM CONSTANT = .21513891+001

```
E
 .845        XO                    BO                   YO                    AREA
       +OR-  55.274        +OR-   6.149       +OR-  .99179+003          .55528+004
              .158                 .211             .14238+003    +OR-  .65468+003

E
1.810        XO                    BO                   YO                    AREA
       +OR- 115.051        +OR-  16.869       +OR-  .99  +002          .72129+003
              .982                5.700             .298  +002    +OR-  .26318+003

E
2.120        XO                    BO                   YO                    AREA
       +OR- 134.815        +OR-  21.825       +OR-  .45 63+002          .9    +003
             1.721                8.959             .17725+002    +OR-  .18252+003

OLD GAIN =
BASE LINE SHFT  .605597-001 INTERCEPT = .258108 +001 NEW GAIN = .4144175-001
                                                    .145000-001  RATIO =   .1  060 +003

E
 .845        XO                    BO                   YO                    AREA
       +OR-  55.316        +OR-   7.750       +OR-  .86456+003          .55649+004
              .144                 .223             .99316+002    +OR-  .46608+003

E
1.810        XO                    BO                   YO                    AREA
       +OR- 124.444        +OR-  23.217       +OR-  .87976+002          .75136+003
              .939                4.085             .22449+002    +OR-  .21050+003

E
2.120        XO                    BO                   YO                    AREA
       +OR- 146.316        +OR-  35.145       +OR-  .39546+002          .51544+003
             1.964               13.085             .13593+002    +OR-  .17957+003
```

NON SHIFTED SPECT

WT FACTORS = Y

BR-1

DECAY AND IRR CORRECTION FACTORS

10 BR-1 = .10000+007 CU64 = .11372+007 AL28 = -.11512+026 S37O = -.46870+015 NA24 = .11159+007
K420 = .11434+007 CL38 = .15817+008 MN56 = .19483+007 MG27 = -.52790+011

COMP CA SPECT

CORRELATION COEFF

EFF(IN PER CENT) = .816067062318+000

CROSS PRODUCT MATRIX

INV CROSS PRODUCT MATRIX

INV ERROR =   .1350641-04

IDENTITY MATRIX

INTERFERENCES IN PER CENT

	CU64	AL28	S37O	NA24	CA49	K42O	CL38	MN56	MG27
BR-1	.32411+002	.37402+000	.32650-002	.48418-001	.59006-002	.35862+000	.16165-001	.35861+001	.25622+001
CU64	.16841-001	.58028+000	.17622+000	.64588+000	.71681-002	.27169+000	.66681-001	.25562+000	
AL28	.65547-001	.64543+001	.46608+000	.81572+001	.29562+001	.11667+002	.28666-001		
S37O	.55668+001	.98812+002	.16771+000	.45628+002	.45855+000	.48765+000			
NA24	.13833+002	.18322-001	.38089+001	.95915+000	.28908+001				
CA49	.12833+000	.20485+002	.76411+000	.55667+000					
K42O	.18593+001	.10365+000	.31512+001						
CL38	.14866+001	.19541-002							
MN56	.32414+002								

(ATRANS * OMEGA * RHO)
10   .29173+007 .22329+007 .17659+009 .26198+005 .58163+007 .26043+006 .47587+005 .52770+007 .15573+009 .14277+007

ISOTOPE REMOVED AL28

ISOTOPE REMOVED S370

ISOTOPE REMOVED CA49

ISOTOPE REMOVED MG27

ITERATION, 0 OF 0 MAX ITER

	BR-1	CU64	NA24	K420	CL38	MN56
SOL (PPM)	.5021+002	-.4285+002	.3260+002	.2822+005	.2530+004	.2405+003
STD DEV	.5909+002	.4629+002	.9474+001	.2121+004	.2928+003	.2405+003
T VALUES	.9512+000	-.9279+000	.3420+001	.1331+002	.8643+001	.2723+001
						.8831+002

F VALUE = .1923+002 CORR COEF = .9944+000

ISOTOPE REMOVED CU64

ITERATION, 0 OF 0 MAX ITER

	BR-1	NA24	K420	CL38	MN56
SOL (PPM)	.2559+002	.3267+002	.2828+005	.2536+004	.2405+003
STD DEV	.4108+002	.9467+001	.2118+004	.2928+003	.2723+001
T VALUES	.6229+000	.3451+001	.1335+002	.8663+001	.8831+002

F VALUE = .2307+002 CORR COEF = .9943+000

ISOTOPE REMOVED BR-1

ITERATION, 0 OF 0 MAX ITER

	NA24	K420	CL38	MN56
SOL (PPM)	.3287+002	.2840+005	.2523+004	.2405+003
STD DEV	.9462+001	.2109+004	.2920+003	.2544+001
T VALUES	.3474+001	.1347+002	.8641+001	.9454+002

F VALUE = .2884+002 CORR COEF = .9943+000
DEG OF FREEDOM = 111. QUAL OF FIT = .112+001
ABS DEV PER PT = .423n796+001 NO OF PTS = 116

CHN	EXP	CALC	RES	CHN	EXP	CALC	RES
1	.17566+003	.17585+003	-.18628+000	2	.16875+003	.17321+003	-.44604+001
3	.15773+003	.17085+003	-.13125+002	4	.15597+003	.17339+003	-.17419+002
5	.15677+003	.17050+003	-.37254+001	6	.17798+003	.17361+003	.43741+001
7	.17002+003	.17405+003	-.49274+001	8	.17930+003	.17730+003	.19975+001
9	.18100+003	.17037+003	.46335+001	10	.18750+003	.17716+003	.10633+002
11	.15777+003	.18251+003	-.52540+001	12	.17477+003	.17316+003	.16155+001
13	.16883+003	.15254+003	.16287+002	14	.14786+003	.13722+003	.10643+002
15	.11495+003	.11465+003	.29540+000	16	.98532+002	.94630+002	.39021+001
17	.77262+002	.78710+002	-.14452+001	18	.98926+002	.97119+002	-.19283+000
19	.62338+002	.50360+002	-.19779+001	20	.70275+002	.75997+002	-.52707+001
21	.11684+003	.11924+003	-.24038+001	22	.22212+003	.22972+003	-.75937+001
23	.41946+003	.43414+003	-.14676+002	24	.69907+003	.72017+003	-.21100+002
25	.89721+003	.87507+003	-.21240+002	26	.86145+003	.83558+003	.25863+002
27	.59672+003	.59906+003	-.32456+001	28	.32377+003	.32346+003	.30975+000
29	.15055+003	.14109+003	-.85586+001	30	.64419+002	.65359+002	-.94002+000
31	.34990+002	.33200+002	-.17987+001	32	.28600+002	.28609+002	-.93067-002
33	.34532+002	.30702+002	-.37339+001	34	.24820+002	.30303+002	-.54829+001
35	.30266+002	.29227+002	-.10390+001	36	.28629+002	.31130+002	-.25014+001
37	.28128+002	.31738+002	-.36105+001	38	.33535+002	.32550+002	.98527+000
39	.37197+002	.32278+002	-.49193+001	40	.37003+002	.32924+002	.40792+001
41	.33506+002	.31155+002	.235..	42	.29003+002	.30072+002	-.10084+001
43	.25731+002	.32655+002	-.59249+001	44	.33949+002	.32123+002	.18257+001
45	.31297+002	.32209+002	-.91213+000	46	.33047+002	.32912+002	.13581+000
47	.35414+002	.32130+002	.32846+001	48	.33687+002	.34312+002	-.62451+000
49	.37366+002	.34104+002	.32632+001	50	.33827+002	.37184+002	-.33569+001
51	.37162+002	.34504+002	.26580+001	52	.31805+002	.35216+002	-.34095+001
53	.37157+002	.34902+002	.21644+001	54	.35012+002	.34101+002	.91156+000
55	.31106+002	.36717+002	-.55113+001	56	.32489+002	.38151+002	-.56614+001
57	.38386+002	.33907+002	.43638+001	58	.40115+002	.34512+002	.55023+001
59	.32963+002	.32885+002	.77207-001	60	.37301+002	.41598+002	-.52797+001
61	.26178+002	.35855+002	-.96796+001	62	.46193+002	.41598+002	-.45953+001
63	.52769+002	.49355+002	-.33808+001	64	.52764+002	.54985+002	-.22210+001
65	.58640+002	.59554+002	-.91408+000	66	.58613+002	.58479+002	.13405+000
67	.55051+002	.52672+002	-.23793+000	68	.49992+002	.48030+002	.19621+001
69	.42837+002	.39027+002	.35094+001	70	.31557+002	.34304+002	-.27470+001
71	.34163+002	.33209+002	.86353+000	72	.34735+002	.29685+002	.50498+001
73	.29502+002	.30973+002	-.14716+001	74	.32342+002	.27225+002	.51175+001
75	.35493+002	.28115+002	-.10378+002	76	.24174+002	.24225+002	-.51674-001
77	.15948+002	.22500+002	-.61480+001	78	.17182+002	.21587+002	-.44057+001
79	.21700+002	.21905+002	-.29559+000	80	.30513+002	.25430+002	.50831+001
81	.42809+002	.34635+002	.81743+001	82	.49910+002	.42639+002	.72709+001
83	.69411+002	.59333+002	.10072+002	84	.83341+002	.73357+002	.99835+001
85	.87581+002	.87374+002	.26727+000	86	.88674+002	.88461+002	.21308+000
87	.76813+002	.32850+002	-.60373+001	88	.62661+002	.67042+002	-.43808+001
89	.50872+002	.52930+002	-.20584+001	90	.30294+002	.30972+002	-.16781+001
91	.24614+002	.27010+002	-.23953+001	92	.17339+002	.12517+002	.48214+001
93	.21470+002	.18075+002	-.27953+001	94	.28276+002	.23084+002	.51920+001
95	.28615+002	.32108+002	-.34926+001	96	.45419+002	.34257+002	.11162+002
97	.40961+002	.39521+002	.14405+001	98	.33367+002	.38026+002	-.45596+001
99	.32458+002	.34381+002	-.19238+001	100	.36894+002	.29365+002	.75282+001
101	.22561+002	.26209+002	-.36451+001	102	.22941+002	.18229+002	.47116+001
103	.12517+002	.13062+002	-.54499+000	104	.95567+001	.95146+001	.42106-001
105	.37146+001	.66055+001	-.29569+001	106	.12737+001	.22261+001	-.95245+000
107	.45252+001	.28503+001	-.16749+001	108	.32491+001	.22519+001	.99713+000
109	.19677+001	.24180+001	-.45031+000	110	.25098+001	.27411+001	-.23125+000
111	.24564+001	.23439+001	.11250+000	112	.18388+001	.19243+001	-.85584-001
113	.24034+001	.18420+001	.56159+000	114	.13628+001	.15009+001	-.13810+000
115	.18578+001	.78464+000	.10731+001	116	.23204+001	.60571+000	.17147+001

T VALUE = 1.5450

SAMPLE WT(GM) = .34700-001 IRR TIME(MIN) = .15000+002 DECAY TIME(MIN) = .58584+002 COUNT TIME
FLUX REF WT(GM) = .33800-001 REF DECAY TIME(MIN) = .10586+004 REF COUNT TIME(MIN) = .20000+00
BKG TIME(MIN) = .60000+002
Y NORM CONSTANT = .22603837+001

```
 E
 .845          XO                    BO
         +OR-  55.270        +OR-   6.470         YO                      AREA
                  .146               .205   +OR-  .12431+004      +OR-   .56045+004
                                                  .15670+003             .71751+003
 E
1.810          XO                    BO
         +OR- 115.012        +OR-  18.544         YO                      AREA
                  .894              3.817   +OR-  .13245+003      +OR-   .10109+004
                                                  .33133+002             .29259+003
 E
2.120          XO                    BO
         +OR- 135.616        +OR-  31.956         YO                      AREA
                 2.102             13.915   +OR-  .77483+002      +OR-   .77635+003
                                                  .29524+002             .38033+003

OLD GAIN = .1593234-001  INTERCEPT = -.3289121-001
BASE LINE SHFT = .2064431+001  NEW GAIN = .1450000-001  RATIO =    .1095427+001


 E
 .845          XO                    BO
         +OR-  58.311        +OR-   8.073         YO                      AREA
                  .132               .211   +OR-  .11166+004      +OR-   .56235+004
                                                  .10986+003             .56299+003
 E
1.810          XO                    BO
         +OR- 123.744        +OR-  22.843         YO                      AREA
                  .821              3.375   +OR-  .12022+003      +OR-   .10184+004
                                                  .25637+002             .26490+003
 E
2.120          XO                    BO
         +OR- 146.161        +OR-  32.909         YO                      AREA
                 1.351              8.686   +OR-  .71904+002      +OR-   .73112+003
                                                  .17654+002             .22529+003
```

SHIFTED SPECT

FACTORS = Y

BR-1

DECAY AND IRR CORRECTION FACTORS

BR-1 = .10000+007   CU64 = .10586+007   AL28 = -.38960+015
CL38 = .35785+007   MN56 = .13603+007   MG27 = .15402+009   S37 = -.88899+010   NA24 = .10493+007   CA49 = .22867+...

AMP-EX SPECT

.2297126+003   .2244725+003   .2258850+003

.6324381+003   .2583831+003   .2395545+003   .1952852+003   .1676197+003
.6315454+003   .2167633+003   .2222247+003   .8001921+002   .9328819+002
.6036369+003   .1155517+003   .9674754+002   .8001921+002   .9328819+002
.6036476+003   .2307926+003   .5557906+003   .9280411+003   .1127122+004
.6020001+004   .7534517+003   .4392478+003   .1930876+003   .9383289+002
.6072077+002   .4224740+002   .4295052+002   .4253016+002   .4803482+002
.6007472+002   .5053133+002   .5299859+002   .5700511+002   .5109887+002
.6046452+002   .5364950+002   .5576894+002   .5400152+002   .5301825+002
.6022993+002   .6150751+002   .6303013+002   .6700931+002   .6580200+002
.6004596+002   .6703160+002   .4667465+002   .6193716+002   .5722430+002
.6035581+002   .4367995+002   .5369910+002   .5056103+002   .5758569+002
.6035686+002   .6323376+002   .8497663+002   .8416606+002   .7357646+002
.6028037+002   .6762220+002   .6645231+002   .6188546+002   .6828502+002
.6056512+002   .8057594+002   .8304943+002   .7504135+002   .7207875+002
.6033955+002   .5855152+002   .4859423+002   .4017473+002   .4862008+002
.6062016+002   .8357803+002   .1044131+003   .1226334+003   .1141179+003
.6138165+003   .9862554+002   .7331525+002   .5483823+002   .4051833+002
.6005474+002   .3303230+002   .4370530+002   .4974336+002   .6666206+002
.6074202+002   .6503623+002   .6889792+002   .6549686+002   .5917711+002
.6002030+002   .3581820+002   .2226229+002   .1870814+002   .1462289+002
.6032541+001   .3396577+000   .1714335+001   .5014632+000   .2686060+001
.6017827+000   .9054753+000   .1709822+001   .2537738+001   .3221845+001
.6005970+001

ELATION COEFF

.10000+001   .3010+000   .3010-001   .2176-002   .147-002   .4047-002   .56829-001   .50974-001   .2475+000   .20757+000
.3105+000   .10000+001   .10682-001   .14354-002   .24452-002   .21194-002   .17049-001   .15148-001   .94383-001   .63843-001
.3010-001   .10682-001   .10000+001   .87122-002   .52895-001   .15303-001   .21246+000   .29477+000   .25007+000   .88114-001
.2176-002   .14354-002   .87122-002   .10000+001   .72645+000   .98010+000   .58261-002   .18240-001   .22986-001   .38437-002
.147-002   .24452-002   .52895-001   .72645+000   .10000+001   .80214+000   .21043-001   .45856-001   .45813-001   .20842-001
.4047-002   .21194-002   .15303-001   .98010+000   .80214+000   .10000+001   .10188-001   .32387-001   .31805-001   .68107-002
.56829-001   .17049-001   .21246+000   .58261-002   .21043-001   .10188-001   .10000+001   .18753+000   .13945+000   .12339+000
.50974-001   .15148-001   .29477+000   .18240-001   .45856-001   .32387-001   .18753+000   .10000+001   .21191+000   .10325+000
.2475+000   .94383-001   .25007+000   .22986-001   .45813-001   .31805-001   .13945+000   .21191+000   .10000+001   .52656+000
.20757+000   .63843-001   .88114-001   .38437-002   .20842-001   .68107-002   .12339+000   .10325+000   .52656+000   .10000+001

IN PER CENT) =   .450467209876+000

CROSS PRODUCT MATRIX

```
10   .11416+010   .87900+009   .11957+011   .19545+007   .47235+009   .20412+008   .44646+007   .37169+009   .16162+011   .16296+009
 .87909+009   .17765+010   .75959+010   .15335+007   .31575+009   .17108+008   .30505+007   .25276+009   .12272+011   .12668+009
 .11957+011   .75959+010   .30406+013   .18402+009   .60761+011   .19019+010   .44551+009   .46128+011   .82645+012   .61520+010
 .19545+007   .15335+007   .18402+009   .12784+007   .14600+009   .98591+007   .47836+005   .74402+007   .16246+009   .83314+005
 .47235+009   .31575+009   .60761+011   .14600+009   .22953+011   .11964+010   .12182+008   .15807+010   .30733+011   .25996+009
 .20412+008   .17108+008   .19019+010   .98691+007   .11954+010   .77738+008   .49328+006   .77312+008   .14902+010   .86483+007
 .44646+007   .30505+007   .44551+009   .47836+005   .12182+008   .49328+006   .30724+006   .11696+008   .19618+009   .23142+007
 .37169+009   .25276+009   .46128+011   .74402+007   .15807+010   .77312+008   .11696+008   .23741+010   .21258+011   .18609+009
 .16162+011   .12272+011   .82643+012   .16246+009   .30733+011   .14902+010   .19618+009   .21258+011   .89823+012   .81740+010
 .16295+009   .12668+009   .61520+010   .83314+005   .25996+009   .86483+007   .23142+007   .18609+009   .81740+010   .14126+009
```

INV CROSS PRODUCT MATRIX

```
10  .17696-008 -.71306-009   .18075-011 -.11813-008 -.14052-010   .44559-009 -.52353-008 -.14136-010 -.15991-010 -.69644-009
 -.71306-009   .91595-009   .20750-012   .13970-007   .27134-010 -.22194-008   .32843-009 -.21428-010 -.17030-011   .16225-009
  .18075-011   .20750-012   .61999-012 -.71324-009   .38617-011   .15176-009 -.45175-009 -.72961-011 -.48497-012   .17568-010
 -.11813-008   .13970-007 -.71324-009   .62698-004   .80851-007 -.92599-005   .53759-006   .58842-007 -.83652-009 -.66311-007
 -.14052-010   .27134-010   .38617-011   .80851-007   .34640-009 -.15630-007   .12195-007 -.87222-010   .36868-011 -.34355-009
  .44559-009 -.22194-008   .15176-009 -.92599-005 -.15630-007   .15630-007 -.14373-005 -.91699-008 -.18920-009 -.14712-007
 -.52353-008   .32843-009 -.45175-009   .53759-006   .12195-007 -.14373-005   .91654-007   .46404-005 -.10810-007 -.45585-007
 -.14136-010 -.21428-010 -.72961-011   .58842-007 -.87222-010 -.91699-008   .46404-005   .73216-009 -.61546-011 -.60567-010
 -.15991-010 -.17030-011 -.48497-012 -.83652-009   .36868-011 -.18920-009 -.10810-007 -.61546-011   .33232-011 -.14384-009
 -.69644-009   .16225-009   .17568-010 -.66311-007 -.34355-009 -.14712-007 -.45585-007 -.60567-010 -.14384-009   .16343-007
```

INV ERROR =   .8257627-005

IDENTITY MATRIX

```
10   .10000+001   .11176-007 -.11921-006 -.58208-010 -.24214-007 -.11642-008   .43656-010 -.11176-007 -.83447-006 -.83819-008
  .20265-007   .10000+001   .74506-007   .23647-009   .37253-008   .11496-008   .14552-010   .46566-009 -.11176-007   .29802-007   .69849-009
  .40745-009   .87311-010   .10000+001 -.95497-011   .23855-008 -.28012-009   .77307-011   .84401-009   .74506-008 -.58208-010
  .00000   .83447-006   .43106-003   .10000+001   .16370-003   .14432-004   .33528-007   .85831-005   .76294-004   .17881-005
 -.19073-007   .18626-008 -.29802-007   .48858-008   .10000+001   .42171-007 -.65484-010 -.74506-008   .11921-006 -.41910-008
 -.47684-006 -.44703-007 -.40054-004   .20256-007 -.68843-005   .10000+001 -.93132-008   .38743-005 -.45776-004 -.41723-006
  .00000   .00000   .34332-004   .27940-008   .59605-006   .74506-007   .10000+001 -.11921-006   .00000 -.11921-006
  .60028-008   .46566-009   .37253-008 -.15793-008 -.36080-007   .16953-008 -.11096-009   .10000+001 -.52154-007   .46566-009
  .29802-009 -.23283-009 -.74506-008 -.40563-009 -.48429-007 -.29686-008   .36380-011 -.46566-009   .10000+001   .11642-008
  .29802-007   .00000 -.95367-006 -.12806-008   .00000 -.14901-007 -.46566-009   .59605-007   .00000   .10000+001
```

INTERFERENCES IN PER CENT

	CU64	AL28	S370	NA24	CA49	K420	CL38	MN56	MG27
BR-1	.31370+002	.29777+000	.12575-002	.52211-001	.78065-002	.33379+000	.15423-001	.43482+001	.16772+001
CU64		.75818-002	.33985+000	.23205+000	.37415+000	.25378-002	.68469-001	.95285-001	.17587+000
AL28			.13087+001	.59437+001	.25843+001	.70934+001	.11727+002	.11415+002	.30461+001
S370				.30098+002	.95149+002	.99334-001	.75425+001	.33584+000	.42914+000
NA24					.49066+002	.92524-001	.29996+001	.11807+001	.20849+001
CA49						.12565+000	.79903+001	.74939+000	.92140+000
K420							.34384+001	.20004+000	.27401+001
CL38								.15568+001	.30660-001
MN56									.38096+002

(ATRANS * OMEGA * RHO)

| 10 | .30583+007 | .23408+007 | .18512+009 | .27464+005 | .60974+007 | .27302+006 | .49835+005 | .55321+007 | .16325+009 | .14967+007 |

```
ISOTOPE REMOVED AL28

ISOTOPE REMOVED S370

ITERATION,  0 OF   0 MAX ITER

               BR-1         CU64         NA24         CA49         K420         CL38         MN56          MG27
SOL(PPM)     .7947+002    .5153+002    .5327+002   -.2857+0n5    .3464+005    .2770+004    .2119+003
STD DEV      .7598+002    .5682+002    .1525+002    .6142+0n5    .2401+004    .9364+002    .3031+001   -.4250+004
T VALUES     .1046+001    .9065+000    .3278+001   -.4852+0n1    .1443+002    .2958+002    .6902+002   -.2359+005
                                                                                                       -.1802+000
 F VALUE =   .1434+002  CORR COEF =    .9891+000

ISOTOPE REMOVED CA49

ITERATION,  0 OF   0 MAX ITER

               BR-1         CU64         NA24         K420         CL38         MN56          MG27
SOL(PPM)     .8202+002    .4785+002   -.1536+002    .3507+0n5    .2772+004    .2112+003   -.4250+004
STD DEV      .7596+002    .5680+002   -.7274+001    .2398+0n4    .9364+002    .3022+001   -.2350+005
T VALUES     .1080+001    .8423+000   -.2112+001    .1462+0n2    .2960+002    .6988+002   -.1808+000
 F VALUE =   .1638+002  CORR COEF =    .9884+000

ISOTOPE REMOVED NA24

ITERATION,  0 OF   0 MAX ITER

               BR-1         CU64         K420         CL38         MN56          MG27
SOL(PPM)     .8302+002    .4823+002    .3450+005    .2750+0n4    .2107+003   -.4250+004
STD DEV      .7595+002    .5680+002    .2397+004    .9319+0n2    .3001+001   -.2350+005
T VALUES     .1093+001    .8500+000    .1456+002    .2951+0n2    .7019+002   -.1808+000
 F VALUE =   .1911+002  CORR COEF =    .9882+000

ISOTOPE REMOVED MG27

ITERATION,  0 OF   0 MAX ITER

               BR-1         CU64         K420         CL38         MN56
SOL(PPM)     .8184+002    .4857+002    .3482+005    .2750+0n4    .2103+003
STD DEV      .7520+002    .5663+002    .2371+004    .9336+0n2    .2181+001
T VALUES     .1088+001    .8577+000    .1469+002    .2945+0n2    .9642+002
 F VALUE =   .2293+002  CORR COEF =    .9882+000

ISOTOPE REMOVED CU64

ITERATION,  0 OF   0 MAX ITER

               BR-1         K420         CL38         MN56
SOL(PPM)     .1174+003    .3477+005    .2747+004    .2103+0n3
STD DEV      .5147+002    .2368+004    .9334+002    .2181+0n1
T VALUES     .2282+001    .1468+002    .2943+002    .9643+0n2
 F VALUE =   .2866+002  CORR COEF =    .9882+000
DEG OF FREEDOM = 111.  QUAL OF FIT =    .340+001
ABS DEV PER PT =   .7448490+001 NO OF PTS = 116
```

CALC · RES · CN · EXP · CALC · RES

T VALUE = 1.6450

APPENDIX M

-LISTING OF THE UPDATING PROGRAMS

The first program is used to record the content of the magnetic tape obtained from NEA-CPL to the main storage of a UNIVAC-1106 computer used in Boğaziçi University.The main program and the sample problem data were recorded on to the same file.The main program and the sample input data are loaded separetely into two different files,CORGAM and DAFCA respectively The namelist is removed from the 96. line to the 4. line due to the requi-rements of the UNIVAC computing system.These are done by the help of the 2. and 3. programs.The 4. program is used to update the coding symbols for UNIVAC-1106 Card Reader and Line Printer.In order to execute the program by the sample input data,the 5. program is used to remove the main program into the 2.cycle of the file,because the first cycle contains the program in data form,by removing it to the 2. cycle,it is transformed into an executable form.Finally the 6. program is used to run the program using the sample data as input.

PROGRAM-1   Records the tape in the main storage

```
@RUN
@ASG,T,J      T.,6C9,D80218
@MOVE   T.,7
@DELETE,C     BOGRUN.
@ASG,UP       BOGRUN.
@USE          F.,BOGRUN.
@COB,ISE
        IDENTIFICATION DIVISION .
        PROGRAM-ID. TEYP-OKUMA.
        ENVIRONMENT DIVISION.
        CONFIGURATION SECTION.
        SOURCE-COMPUTER. U-1106
        OBJECT-COMPUTER. U-1106
        INPUT-OUTPUT SECTION.
        FILE-CONTROL.
            SELECT T ASSIGN TO UNISERVO T.
        DATA DIVISION.
        FILE SECTION.
        FD T
            LABEL RECORDS OMITTED
            RECORDING MODE IS F.
        01  T-REC PIC X(80).
        FD F
            RECORDING MODE IS SDF.
        01  F-REC PIC X(80).
        PROCEDURE DIVISION.
        AC. OPEN INPUT T WITH NO REWIND.
        OPEN OUTPUT F.
        OKU. READ T AT END GO TO SON.
            MOVE T-REC TO F-REC.
            WRITE F-REC.
            GO TO OKU.
            SON. CLOSE T WITH NO REWIND.
        CLOSE F.
            STOP RUN.
@MAP,IN
@XQT
@DATA,L      BOGRUN.
@FIN
```

PROGRAM-2   1.Update of main program

```
@RUN
@ASG,A       BOGRUN.
@DELETE,C    CORGAM.
@ASG,UP      CORGAM.
@DATA,L      BOGRUN.,CORGAM.
-4
     NAMELIST /NAM1/ISOCHN,MODE,NBKGD,NUBKG,NSHFT,LPP,NORM,NCTIN
  1NAREA,NCHCU,NCULL,NCUUL,NRHO,NUMVAR,NVAR,NREFS,ITER,NR,NWW,
  2LOCHN,NHICHN,NCHAN,MC,MVAR/NAM2/C/NAM3/T,DECAY,COUNT,WT,CUC
  3T,WTCU,AREA,CUDEC,BKGTIM,FHRL,UP,XNCOM
-93,96
▽1296,1851
@END
@FIN
```

PROGRAM-3   Load sample problem data

```
@RUN
@ASG,A       BOGRUN.
@DELETE,C    DAFCA.
@ASG,UP      DAFCA.
@DATA,L      BOGRUN.,DAFCA.
-1,1295
@END
@FIN
```

PROGRAM-4   2. Update of main program

```
@RUN
@ASG,A       CORGAM.
@ED,L        CORGAM.,CORGAM.
C /READ(1,/READ(5,/ ALL
C /WRITE(3,/WRITE(6,/ ALL
@END
@FIN
```

PROGRAM - 5

```
@RUN
@ASG,A      CORGAM.
@ASG,UP     CORGAM(÷1).
@FTN,US     CORGAM(÷1).
@ADD,DP     CORGAM.
@FIN
```

3. Update of main program.

PROGRAM - 6

```
@RUN
@ASG,A       CORGAM.
@ASG,A       DAFCA.
@DELETE,C 2.
@DELETE,C 10.
@ASG,UP      2.
@ASG,UP      10.
@FTN,S       CORGAM.MAIN
@PREP        CORGAM.
@MAP,I     .CORGAM.MAIN
IN CORGAM.MAIN
LIB CORGAM.
@XQT         CORGAM.MAIN
@ADD,DP     DAFCA.
@FIN
```

Run of main program with sample problem inputdata.

APPENDIX N

The following is a list of the computer programs coded for experimental data processing, used in common neutron activation analysis.

A-Computer codes available in ARGONNE NATIONAL LABORATORY (ANL-7411)

1- TOAD :"A computer code for processing gamma-ray spectra"
Reactor code abstract: 333, Coded for: UNIVAC-1108
Language: Fortran IV   Issued at: June,1968

2- CORGAM :"A correlation algorithm for gamma-ray spectra"
Reactor code abstract: 390, Coded for: IBM 360/50
Language: Fortran IV-G   Issued at: May,1969

3- ALPHA-M :"Resolution of gamma-ray spectra" (improved version of ALPHA)
Reactor code abstract: 413, Coded for: IBM 360
Language: Fortran IV,CPL   Issued at: December 1970

4- GSSLRN1B :"Least squares photopeak spectra code"
Reactor code abstract: 457, Coded for: UNIVAC-1108
Language: Fortran IV,CPL   Issued at: June 1972

5- GASPAN :"Complex gamma-ray spectra analysis"
Reactor code abstract: 485, Coded for: CDC 6600
Language: Fortran IV   Issued at: January 1972

B-Computer codes available in NEA-CPL,Ispra

6- GRETEL :"Ge(Li) gamma spectrum unfolding"
Program abstract: E 433   Coded for: IBM 370
Language: Fortran IV,CPL,Assembler

7- RADAK :"Neutron and gamma spectrum unfolding"
Program abstract: E 487   Coded for: IBM 370
Language: Fortran IV