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SHARDA - A PROGRAM FOR SAMPLE HEAT, ACTIVITY, REACTIVITY AND DOSE ANALYSIS

by

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ABSTRACT

A computer program SHARDA (Sample Heat, Activity, Reactivity and Dose Analysis) has been developed for safety evaluation of Pile Irradiation Request (PIR) for various nonfissile materials in the research reactor CIRUS. The code can also be used, with minor modifications, for PIR safety evaluations for the research reactor DHRUVA, now being commissioned. Most of the data needed for such analysis like isotopic abundances, their various nuclear cross-sections, gamma radiation and shielding data have been built in the code for all nonfissile naturally occuring elements. The PIR safety evaluations can be readily carried out using this code for any sample in elemental, compound or mixture form irradiated in any location of the reactor.

This report describes the calculational model and the input/ output details of the code. Some earlier irradiations carried out in CIRUS have been analysed using this code and the results have been compared with available operational measurments.

SHARDA - A PROGRAM FOR SAMPLE HEAT, ACTIVITY, REACTIVITY AND DOSE ANALYSIS

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1 INTRODUTION

Irradiation of different materials for various purposes like isotope production, material testing etc. is one of the main activities of a research reactor. Samples(nonfissile materials), when put inside a reactor, lead to a loss of reactivity of the reactor due to the parasitic absorption of neutrons in them. This causes a LOAD on the available excess reactivity of the reactor. The samples under irradiation generate HEAT by absorbing gamma rays produced in the reactor as well as in the sample itself as capture gammas. The irradiated sample is radioactive and emits its characteristic gammas causing biological damage to tissues of persons handling it which is assessed by the DOSE RATE due to all the gammas of the sample. It is, therefore, imperative to evaluate all these entities, viz, Reactivity Load, Sample Heating and Dose Rate from the irradiated sample for the safe operation of the reactor as well as for the safety of the personnel before permitting the sample to be introduced in the reactor. These evaluations were carried out on desk calculator on a routine basis to approve the Pile Irradiation Requests(PIR) for various materials by the users of CIRUS. To get rid of the monotonous routine desk calculations and also the possible human errors while collecting the various input data or elsewhere, a computer program SHARDA has been developed to carryout these evaluations.

The relevant basic data for all the elements of interest have been built in the code and only a bare minimum input like sample mass, its chemical formula, density, irradiation and cooling times,location in the reactor and its geometry are to be supplied by the evaluator. The program has been written such that with few minor changes it can be used for such evaluations for the reactor DHRUVA after its commissioning.

2 METHOD OF CALCULATION

The entities of interest, viz, sample reactivity load and its heating rate during irradiation and its radioactivity(curies) as well as the unshielded dose rate after irradiation are calculated in the code. The code also calculates the lead shielding requirements for the dose rate to be within permissible range. If the shielding requirements are large the code calculates whether cooling of the sample for some more time can help reducing the shielding requirement and to what extent.

The formalism of these calculations is described in the following paragraphs. All the calculations are carried out in one group model of neutron energy.

2.1 Flux Depression Factor

When a sample is introduced in a tray rod position, the flux inside it, strictly speaking, varies from point to point. It is maximum at the surface and decreases as one moves to the interior. If ϕ_0 is the flux at surface of the sample and ϕ_A that averaged over the sample, the ratio ϕ_A/ϕ_0 is called the Flux Depression Factor. The flux depression factor can be calculated by solving the neutron diffusion equation inside the sample for the given geometry with appropriate boundary conditions. The symbols in the following discussion have their usual meanings.

2.1.1 Spherical Geometry

In the spherical geometry the neutron diffusion equation for a nonfissile material is

$$D\Delta^2\phi - \Sigma_A\phi = 0$$

$$d^2\phi/dr^2 + (2/r)d\phi/dr - k^2\phi = 0$$

where: $k^2 = (\Sigma_A / D)$

which gives a general solution as

$$\Phi(r) = \frac{Ae^{kr} + Be^{-kr}}{r} \qquad (1)$$

using the boundary conditions

(a) At $r = 0$, $r^2 d\Phi/dr = 0$ and

(b) At $r = R$, $\Phi = \Phi_0$

we will obtain

$$A = -B = \frac{R\,\Phi_0}{(e^{kR} - e^{-kR})} \qquad (2)$$

using these values of the constants A and B in the solution for $\Phi(r)$ given by eqn (1) we get the flux depression factor, f, as

$$f = \Phi_A / \Phi_0 = \frac{\int_0^R 4\,\pi\, r^2\, \Phi(r)\, dr}{\Phi_0 \int_0^R 4\,\pi\, r^2\, dr}$$

$$f = \frac{3}{k^2 R^2} (\ kR\ \mathrm{Coth}(kR) - 1\ ) \qquad (3)$$

2.1.2 Cylindrical Geometry

Many times the samples to be irradiated are in the pencil form (right circular cylinder). For a long cylinder, the axial variation of neutron flux may be neglected and only the radial variation is accounted. In the present code the axial variation of neutron flux in the sample has been ignored which is not quite accurate for the estimation of the flux depression factor in cylinders of finite height.

However, it appears to be satisfactory from operational point of view.

The flux variation is, then, given by

$$\phi(r) = A\, I_o(kr) \tag{4}$$

Using the boundary condition

$\phi = \phi_s$ at $r = R$ we get,

$$\phi_s = A\, I_o(kR)$$

or $$A = \phi_o / I_o(kR) \tag{5}$$

which on substitution in (4) gives:

$$\phi(r) = \phi_o I_o(kr)/I_o(kR) \tag{6}$$

The Flux Depression Factor f is given by

$$f = \int_o^R 2\pi r \phi(r) dr \Big/ \phi_o \int_o^R 2\pi r dr$$

$$= \frac{2\int_o^R I_o(kr) r dr}{R^2\, I_o(kR)}$$

$$= \frac{2 I_1(kR)}{k\, R\, I_o(kR)} \tag{7}$$

2.2 Reactivity Load

The neutron balance equation in a reactor can be written in the operator form as :

$$H\,\phi = \lambda_s\, F\,\phi \tag{8}$$

where:

$$H = (\Sigma_A - D\,\Delta^2)$$

$$F = \nu\,\Sigma_f$$

$$\lambda_0 = 1/k_0$$

Now consider a very small perturbation has taken place in the system, as would be the case by inserting a small sample in tray rod. The new equation would be:

$$(H + \delta H)\phi_1 = (\lambda_0 + \delta\lambda)(F + \delta F)\phi_1 \tag{9}$$

By writing the adjoint equation and with some algebra, the equations (8) and (9) can be solved [1] as :

$$\delta k/k = -\delta\lambda/\lambda_0 = \frac{-\langle \phi^+, (\delta H - \lambda_0 \delta F)\ \phi_1 \rangle}{\lambda_0 \langle \phi^+, (F + \delta F)\ \phi_1 \rangle} \tag{10}$$

Since we are considering only nonfissile samples, $\delta F=0$ and hence

$$\delta k/k = \frac{-\langle \phi^+, \delta H\ \phi_1 \rangle}{\lambda_0 \langle \phi^+, F\ \phi_1 \rangle}$$

In one group model, the adjoint neutron flux is the same as the real neutron flux. Thus in one group model this can be written in the integral form as :

$$\delta k/k = \frac{-\int_{Vs} \phi\ \ \delta\Sigma_A \phi_1 dv - \int_{Vs} \Delta\phi\ .\delta D.\Delta\phi_1\ dv}{\lambda_0 \int_{Vr} \phi\ \ \nu\Sigma_f \phi_1\ dv} \tag{11}$$

Where Vs is the volume of sample and Vr that of reactor. The first term in the numerator represents the absorption effect while the second the leakage effect of the sample. The numerator covers the integration over the volume of the sample only because elsewhere the perturbation is zero(ie,$\delta\Sigma_A = \delta D = 0$). It may be seen that the second term contains the product of $\Delta\phi$ and $\Delta\phi_1$ and is much smaller than the first one containing the product of ϕ and ϕ_1 and, hence, can be neglected for the evaluation of reactivity load of sample absorber materials.

The reactivity load of the sample would, therefore, be given by:

$$\delta k/k = \frac{-k_0 \int_{Vs} \phi \;\; \delta\Sigma_A \phi_1 \; dv}{\int_{Vr} \phi \;\; \nu\Sigma_f \phi_1 \; dv}$$

Since the denominator is the integration over the whole reactor and the flux is assumed not to be perturbed elsewhere except in the small region of the sample itself, the term ϕ_1 can be replaced by ϕ in the denominator without any loss of accuracy.

The numerator covers integration over the sample only, the perturbed flux ϕ_1 can be replaced by the average flux $f\phi$ in the sample(f being the flux depression factor). Thus

$$\delta k/k = \frac{-k_0 \; f \; \delta\Sigma_A \int_{Vs} \phi^2 \; dv}{\int_{Vr} \phi \;\; \nu\Sigma_f \phi \; dv}$$

Suppose in the tray rod, the sample is installed at a position having unperturbed flux ϕh. Then the reactivity change due to its introduction will be

$$\delta k/k = \frac{-f \; \delta\Sigma_A \; k_0 \; \phi_h^2 \; Vs}{\int_{Vr} \phi^2 \nu \, \Sigma_f \, dv} \qquad (12)$$

In Cirus reactor the reactivity change due to introduction of a white absorber ($f = 1.0$) in the tray rod at an elevation of maximum flux (say ϕm) has been experimentally evaluated as .0299 mk for a total absorption cross section of 1sq.cm (ie, $\delta\Sigma_A Vs$ = 1sq.cm). Therefore,

$$.0299 \times 10^{-3} = -k_0 \; \phi_m^2 \, / \int_{Vr} \phi^2 \nu \, \Sigma \, dv \qquad (13)$$

from equation (12) and (13) we get

$$\delta k/k = .0299 \; f \; Vs \; \delta\Sigma_A (\phi_h^2 / \phi_m^2) \times 10^{-3} \qquad (14)$$

2.3 Heating Rate in the Sample

The sample inside the reactor absorbs neutrons and emits the capture gammas. These gammas deposit part of their energy within the sample before escaping it. Apart from these, the gammas and fast neutrons produced elsewhere in the reactor also interact with the sample and deposit a part of their energy during the process. The energy imparted to the sample due to alpha, beta and gamma rays of radioactivity produced in the sample is relatively very small and has been ignored in this code.

All these interactions lead to the heating of the sample which should be within limits for safety considerations. The precise evaluations of these interactions require involved calculations and that too would have some uncertainties. However, an effort is made to have rough estimates of the heating in the sample by making some simplifying assumptions.

2.3.1 Capture Gamma Heating

We assume that Sv photons of energy Eo(MeV) are produced per cc of the sample, uniformly. The energy deposition buildup factor of these photons can be given by a linear formula

$$B.F. = 1 + a_1 \mu R$$

The average rate of energy deposition per cc of the sample of spherical geometry of radius R is then given [2] by:

$$\bar{H} = \frac{C_0 E_0 \mu_A Sv[\Psi_0 + a_1 \Psi_1]}{\mu} \qquad (15)$$

where :

Co = Conversion factor 1.6×10^{-13} (WS/MeV)

μ_A = Energy deposition coefficient for energy Eo (cm^{-1})

μ = Total linear attenuation coefficient (cm^{-1})

$$\Psi_0 = 1 - \frac{[6\mu^2 R^2 - 3 + (3 + 6\mu R)\, e^{-2\mu R}]}{8\mu^3 R^3}$$

$$\Psi_1 = 1 - \frac{[3\mu^2 R^2 - 3 + (3 + 6\mu R + 3\mu^2 R^2) e^{-2\mu R}]}{2\mu^3 R^3}$$

The expression for the energy deposition in the case of an infinitely long solid cylinder of radius R is the same as given by equation (15) but with a changed expression for Ψ_0 and Ψ_1. In this case

$$\Psi_0 = 1 - (2/3)\mu R[2\mu R(k_1(\mu R) I_1(\mu R) + k_0(\mu R) I_0(\mu R) - 2 + (1/\mu R) k_1(\mu R) I_1(\mu R) - k_0(\mu R) I_1(\mu R) + k_1(\mu R) I_0(\mu R)]$$

$$\Psi_1 = 1 - 2I_1(\mu R).k_1(\mu R)$$

In the case of annular cylinder we have approximated it to a solid cylinder of effective radius Reff which conserves the sectional area of the material, i.e.

$$Reff^2 = R_0^2 - R_1^2$$

where R_0 and R_1 are outer and inner radii, respectively. The total energy deposition rate in the sample of volume V will be

$$H = V\,\bar{H}$$

$$= V\ C_0 E_0 \mu_A Sv[\Psi_0 + a_1 \Psi_1]/\mu$$

$$= C_0 SvE_0 (\mu_A/\mu)\ (M/\varrho)[\Psi_0 + a_1 \Psi_1] \qquad (16)$$

where M and ϱ are the mass and density of the sample, respectively. It may be seen that the parameters of this equation are, strictly speaking, dependent on the material and the energies of the photons emitted by them. We have made some approximations to arrive at some global (average) values which may approximately fit to all the elements. The approximations are

$$E_0\ Sv = 8\ \Sigma a\ \phi\ f \qquad MeV/cm^3$$

$$(\mu_A/\varrho) = 0.025 \qquad cm^2/gm$$

$$(\mu/\varrho) = 0.042 \qquad cm^2/gm$$

$$a_1 = 0.65$$

These approximations are based on the assumption that a neutron capture results in the production of 8 MeV of energy in the form of gammas, irrespective of the element in which they are absorbed. The values of (μ_A/ϱ) and (μ/ϱ) adopted here are representative of medium atomic weight elements for a photon energy of about 2 Mev. These parameters are slowly varying functions of photon energy and interacting material and, hence, their global use is expected to give reasonable estimates, though not very accurate, of heating rates for operational purposes.

2.3.2 Core Gamma Heating

The energy deposition rate due to the core gammas in various structural materials was estimated [3] to be around 400 mw/gm in case of maximum slow neutron flux of 1.5 E+14 n/sqcm/sec of the reactor DHRUVA. The same has been scaled down by a factor of 2.5 for CIRUS where the maximum slow neutron flux is 6.5 E+13. In any case this forms a very small fraction of that due to the capture gammas of the sample.

2.4 Sample Radioactivity

Consider a sample with a chemical formula Xi Yj ....(where X, Y, are the natural elements) is to be irradiated in the reactor for ti seconds. These natural elements constituting the sample produce radioactive isotopes with their characteristic decay properties. We are interested in calculating the various species of gamma activities induced in the sample during its irradiation. The indentification of the radioactivities produced along with their strengths is needed for the evaluation of lead shielding required for the sample to keep the dose rate within safe limits.

2.4.1 First Order Effects

Suppose element X has one of the isotopes X1, which by absorbing a neutron becomes radioactive isotope X2. The isotope X2 in turn may be lost by decay or absorbing another neutrton in the reactor. Here, we limit our consideration that the decay or absorption in X2 does not lead to any activity.

Suppose σ_{A1} is the microscopic absorption cross section of the isotope X1 and σ_{C2} is its activation cross section to form X2. λ_2 and σ_{A2} are the decay constant and absorption cross section respectively for isotope X2.

The number of nuclei N1 and N2 of isotopes X1 and X2 respectively at any time during irradiation will be governed by the following equations.

$$dN_1/dt = -\sigma_{A1} \phi N_1 \tag{17}$$

$$dN_2/dt = \sigma_{C2} \phi N_1 - (\lambda_2 + \sigma_{A2}\phi) N_2 \tag{18}$$

The solution of equation (17) with the initial condition

$N_1 = N_1^0$ at t=0 would be

$$N_1 = N_1^0 e^{-\sigma_{A1}\phi t}$$

Putting this solution in equation (18) we get

$$dN_2/dt + (\lambda_2 + \sigma_{A2}\phi)N_2 = \sigma_{C2} \phi N_1^0 e^{-\sigma_{A1}\phi t}$$

This can be solved, with the initial condition $N_2 = 0$ at t=0 to give

$$N_2 = \frac{N_1^0 \sigma_{C2} \phi [e^{-\sigma_{A1}\phi t} - e^{-(\lambda_2 + \sigma_{A2}\phi) t}]}{\lambda_2 + (\sigma_{A2} - \sigma_{A1}) \phi} \tag{19}$$

The radioactivity (disintegrations/sec) A_2 due to this isotope would, therefore, be

$$A_2 = \lambda_2 N_2 = \frac{\lambda_2 N_1^0 \sigma_{C2} \phi [e^{-\sigma_{A1}\phi t} - e^{-(\lambda_2 + \sigma_{A2}\phi) t}]}{\lambda_2 + (\sigma_{A2} - \sigma_{A1}) \phi} \tag{20}$$

If the following approximations are made

$$(\sigma_{A2} - \sigma_{A1})\phi \ll \lambda_2$$

$$\sigma_{A2}\phi \ll \lambda_2$$

$$e^{-\sigma_{A1}\phi t} \approx 1.0$$

then the expression for activity given by equation (20) reduces to the well known relation

$$A_2 = N_1^0 \sigma_{c2} \phi [1 - e^{-\lambda_2 t}] \quad (21)$$

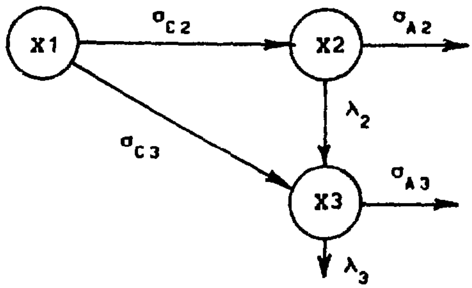
Effectively, this equatioin does not account for the depletion of target as well as that of the produced radioactive nuclei by the absorption of neutrons. These effects may be considerable for long or high flux irradiations. The present code accounts for these effects by using equation (20) rather than the usual approximate expression given by (21).

2.4.2 Threshold Reactions

The radioactivities produced by (n,γ) reactions in different isotopes have, in general, been accounted in this code. However, some isotopes produce radioactivities of considerable importance due to some threshold reactions, like (n, α), due to presence of fast neutrons. For example , irradiation of Al-27 produces Na-24 by (n,α) reaction. For shielding considerations, the radioactivity of Al-28 produced by the capture of thermal neutrons in the reactor is of little concern (execpt for extremely short cooling times) as compared to that of Na-24 produced by (n,α) reactions with fast neutrons in the reactor . This is because Na-24 has a relatively long half life (15 hrs) as compared to that of Al-28 (2.3 mnts) and also because Na-24 emits very hard gammas as compared to those of Al-28. Since all the samples are contained in aluminium capsules, we have included (n,α) reaction for the irradiation of aluminium. The fast flux has been estimated to be about 11% of the thermal flux and the (n,α) cross-section for Al-27 was taken to be 0.6 mb, corresponding to the fission spectrum of neutrons.

2.4.3 Second Order Effects

Let us now consider the case where the isotope X2 may decay to another isotope X3 (or may be another isomeric state of the same isotope X2) which is also radioactive with different characteristics. We further consider that the isotope X1 can also be directly activated to the isotope X3 with an activation cross section of σ_{C3}. This is really the case with many isotopes (e.g. Co-59) which are activated to two isomeric states of the same isotope (Co-60) having different decay characteristics and also one of them decays to the other. In such cases at any time there would exist two species of radioactivities. Pictorially they can be represented as:



Suppose isotope X1 has activation cross sections σ_{C2} and σ_{C3} to form radioactive species X2 and X3, respectively. Further X2 decays to X3 with a decay constant of λ_2. If N_1 represents the initial no. of nuclei of X1 and N1, N2, N3 those of X1, X2 and X3 respectively at any instant then they are governed by the equations

$$dN_1/dt = -\sigma_{A1} \phi N_1 \quad (22)$$

$$dN_2/dt = \sigma_{C2} \phi N_1 - (\lambda_2 + \sigma_{A2} \phi) N_2 \quad (23)$$

$$dN_3/dt = \sigma_{C3} \phi N_1 - (\lambda_3 + \sigma_{A3} \phi) N_3 + \lambda_2 N_2 \quad (24)$$

The solution of equation (22) is

$$N_1 = N_1^0 \, e^{-\sigma_{A1} \phi \, t} \tag{25}$$

Substituting this in (23) and solving with the initial condition N2=0 at t=0, we get

$$N_2 = \frac{N_1^0 \, \sigma_{C2} \phi \left[e^{-\sigma_{A1} \phi \, t} - e^{-(\lambda_2 + \sigma_{A2} \phi) \, t} \right]}{\lambda_2 + (\sigma_{A2} - \sigma_{A1}) \, \phi} \tag{26}$$

Substituting these solutions for N1 and N2 in equation (24) and solving it for N3 with the initial condition N3 = 0 at t=0 we get,

$$N_3 = \frac{B \left[e^{-\sigma_{A1} \phi \, t} - e^{-(\lambda_3 + \sigma_{A3} \phi) \, t} \right]}{\lambda_3 + (\sigma_{A3} - \sigma_{A1}) \phi}$$

$$+ \frac{D \left[e^{-(\sigma_{A2} \phi + \lambda_2) t} - e^{-(\lambda_3 + \sigma_{A3} \phi) \, t} \right.}{\lambda_3 + \lambda_2 + (\sigma_{A3} - \sigma_{A2}) \phi} \tag{27}$$

where B and D are constants given as

$$B = \phi \, N_1^0 \left[\sigma_{C3} + \frac{\lambda_2 \, \sigma_{C2}}{\lambda_2 + (\sigma_{A2} - \sigma_{A1}) \phi} \right]$$

$$D = \frac{\phi \, N_1^0 \sigma_{C2} \, \lambda_2}{\lambda_2 + (\sigma_{A2} - \sigma_{A1}) \phi}$$

Using the expressions for N2 and N3 as given by equation (26) and (27) we calculate the radioactivities due to these species by multiplying by their respective decay constants.

It may be mentioned that this formalism becomes necessary for the cases in which an isotope is activated to another with two isomeric states (with different activation cross sections) one of which decays to the other with certain half life. For example, Sc-81 gets activated to two isomers of comparable half lives, one of which decays to the other. The code calculates the radioactivities due to both the species separately. The cases like formation of Po-210 by the irradiation of Bi-209 and subsequent decay of Bi-210 are also simulated in the code by assigning σ_{c3} as zero in this formalism.

2.4.4 Effect of Cooling

The radioactivity produced during irradiation is reduced by an exponential law, if the sample is allowed to cool for sometime. The net activity $A_2(t_c)$ remaining of a source having initial activity $A_2(0)$ and cooled for tc seconds, is given by

$$A_2(t_c) = A_2(0)\ e^{-\lambda_2 t_c}$$

2.5 Dose Rates of Induced Radioactivities

Various radioactivites are induced in the sample during its irradiation in the reactor. We are interested in evaluating the lead shield requirements for the sample so that the dose rate at 1 foot does not exceed the permissible limit of 200 mR/hr. Alpha and Beta radiations would be easily stopped by a relatively thin layer but it is the gammas which penetrate and require sufficient shielding to reduce the dose rate to permissible limits. The unshielded dose rate D_0 at 1 foot from a gamma source of strength 'C' curies is given by [4]

$$D_0 = 6\ C \sum_{\nu} E\nu\ f\nu$$

where fν refers to the average no. of gammas emitted with energy Eν for each disintegration of the source.

2.5.1 Dose Buildup Factors

The introduction of lead shield around a gamma source reduces the dose rate because some of the radiated photons are lost while collidig with the shielding material. The dose rate at 1 foot due to uncollided photons having traversed a shield thickness of x cm is given by the well known attenuation formula.

$$Dx = D_0 \, e^{-\mu x}$$
$$= 6 \, C \sum_v Ev \, fv \, e^{-\mu x}$$

where D_0 is the unshielded dose rate and Dx that with a shielding of x cm. μ is the total gamma attenuation cross section for the energy of gamma under consideration. However, all the photons that collide with material are not lost and some of them do come out with some reduced energy after making a few scatterings in the material. These photons add to dose rate due to the uncollided photons. This is accounted by defining a term "Buildup Factor" which is the ratio of the actual dose to the uncollided dose at a point. Evidently this would depend on the energy of photons (as μ depends on energy) and the thickness of shield. Their precise estimation requires involved calculations which is really not needed for such analysis. The total attenuation cross section is also a function of photon energy. Both, the total attenuation cross section and the buildup factors are available [4] in a tabular form as a function of energy and thickness. The same have been used to interpolate the μ and B values for the desired energy and shield thickness.

2.5.2 Shielded Dose Rate due to Sample

The shielded dose rate at 1 foot from a gamma source of strength C curies emitting photons of various energies Ev with their fractional yields fv, and having shield of x cm would, therefore, be given by

$$D = 6 \, C \sum_v Ev \, fv \, e^{-\mu x} \; B(Ev, \mu x)$$

where $B(Ev,\mu x)$ is the build up factor for photons of energy Ev with a lead shield thickness of x cm. The dose rates at 1 foot due to the various activities produced in tha sample elements are calculated using the above relation.

2.5.3 Shielded Dose Rates due to the Capsule Activity

As discussed earlier, the contribution of the Na-24 formed by the (n,α) reaction with the aluminium of the capsule containing the sample is significant and at times dominant (in case of low dose rates from sample materials) in the total dose rate due to sample alongwith the capsule.This has been accounted in the code by building in the dose rate at 1 foot due to the saturation activity of Na-24 produced in the capsule at a reference flux value (maximum of circle # 4) for various shield thicknesses, to avoid repetitive calculations. Its dose rate at 1 foot with a desired shield thickness for a particular sample irradiation is derived from the corresponding tabulated saturation dose rate at 1 foot using the proportionality relationship given below.

$$D = D_0 \; (\phi/\phi_0) \; (1 - e^{-\lambda ti}) \; e^{-\lambda t_c}$$

where:

D_0 = Dose rate at 1 foot due to saturation activity in flux position ϕ_0

λ = Decay constant of Na-24 (per hours)

ti = Irrradiation time in hours

t_c = Cooling time in hours

The dose rate due to the capsule is added to the sample dose rate to arrive at the total dose rate at 1 foot due to sample alongwith the capsule.

3 CODE DESCRIPTION

The basic formalism of the code has already been discussed in the previous sections . The flow chart of the code is given in Figure 1 which gives the birds-eye view of the code. Although the flow chart is self explanatory, a brief description of the code is given below.

A large number of input data are required for various constitutent isotopes of a sample and the radioactive isotopes formed during their irradiation. Various data for different elements like their natural isotopic composition, atomic weights, radioactive isotopes formed and their half lives, the energies and the yield of photons radiated by the induced radioactivities, the activation and absorption cross sections of different isotopes etc. remain unchanged irrespective of the sample in which they exist. Such data have been built in the code, once for all, for all the isotopes of interest so that they can internally be picked up for the elements constituting the sample under analysis. These data have been taken from references (2) and (5). The samples are irradiated in fixed locations of the reactor, hence, the neutron fluxes at these locations have also been built in the code. The neutron flux in various irradiating locations (different tiers of tray rods or self-serve), strictly speaking, depends on the core loading and operating heavy water height. However, we have incorporated the flux corresponding to a representative core loading with an operating heavy water height of 295 cms. Effort has been made to reduce the input to be supplied by the user to a bare minimum, i.e., the ones which are sample dependent.

3.1 Code Operation

The code reads the inputs like chemical formula of the material, its mass, density, irradiation required, cooling time after irradiation, its location in the reactor (tray rod tier number, circle number of tray rod. or self-serve position)geometry of the sample and its details (for cylinders). Before starting any calculation the code checks for the correctness of the input, i.e, the tier number, self-serve position or the symbols of the elements of the sample are not beyond the actual range. In case of any error, the code stops after printing the error message to avoid the erroneous output produced inadvertently. The code starts with the calculation of nuclear concentration of various constituent isotopes in the sample. It calculates the flux depression factor for the given sample which is used to calculate the reactivity load and heating rate of the the sample. It subsequently recognises the radioactive isotopes produced and calculates their strengths after irradiation. It proceeds by calculating the strength of various activities after a given cooling time and the dose rate at 1 foot due to the characteristic gammas emitted by the different radioactive isotopes with a uniform shield of 2 inches of lead around it. The dose rate due to Na-24 formed by (n,α) reaction with the aluminium of the capsule is added to that due to the sample material. If the total dose rate at 1 foot is found to be more than the permissible limit of 200 mR/hr, it increases the shield by 1 inch and recalculates the dose rate. It keeps on incrementing the shield thickness until the dose rate at 1 foot is found to be less than 200 mR/hr. If the required lead shield is found to be more than 2 inches and no cooling has been provided, it looks for the reduction of shield thickness to 2 inches by allowing cooling of the sample for 1,2,4,8,24,72,120,240,720 hours respectively for the dose rate at 1 foot to be within the permissible limit. It stops the calculations when either the shield requirement is equal to 2 inches or the total cooling time exceeds 30 days.

3.2 Input Specifications

The inputs required for the code are given in the free format except the chemical formula of the sample. In free format, various parameters are supplied sequentially, seperated by a blank, according to the type(Real or Integer) of the variable. A file of input data is prepared and given a name(say INPT) which is assigned Logical Unit # 5 and is processed by the code to produce an output file(say OTPT) assigned Logical Unit # 6 which gives the relevant summary of the given PIR. The details of the input file are given on next page.

Variable	Description
	Card No. 1 FORMAT (15(A2,I1))
(X(I),M(I), I=1,N)	Identification of the element (left justified) folowed by its atomic multiplicity in the compound for all (say N) elements constituting the sample. (for mixtures atomic multiplicity has no meaning, any value can be given)
	Card No. 2 (Free Format)
NPIR	PIR Number
SMA	Mass of sample (gms) (+ X for compound as given on Card 1) (- X for mixture of elements on Card 1)
DEN	Density of sample (gms/cc) (not used in cylindrical geometry)
TIR	Irradiation required (+ X for X hours of irradiation) (- X for X MWD of irradiation)
TIC	Cooling time (hrs)
NL	Sample locatiion (+ N for T.R. tier no. N from bottom) (- N for S-N position in self serve)
NC	Circle no. for tray rod (for J rod annulus NC = 23) (not used for self serve location)
NG	Geometry of the sample (0=spherical; 1= cylindrical)
PF	Plant Factor

Card No. 3 (Free Format)

(required only for cylindrical geometry)

RO	Outer radius (cm) of the cylinder
RI	Inner radius (cm) of the cylinder (RI=0.0 for solid cylinders)
H	Height (cms) of the cylinder

Card No. 4 (Free Format)

(required only for mixture of elements)

(WP(I),I=1,N)	Weight percentages of constituent elements of the mixture in the order given on Card 1

The input file may contain the inputs for more than one sample (one after the other) all of which will be processed sequentially in a single run. A sample input is given in Appendix- A.

3.3 Output

The output of the code appears in two parts. The first part consists of summary of results which appears on Logical Unit # 6 (with a file name, say OTPT). *This is a one* page output and can be filed for records. It contains the input data of the sample, its reactivity load and heating rate. It also contains the strength of various radioactivities produced after irradiation and cooling and their dose rates at 1 foot. Finally, it gives the shielding requirements for the given cooling time or, if no cooling is provided at various cooling times, to bring down the dose rate at 1 foot within the permissible limits.

The second part of the output appears on the terminal and can be stored and printed if a COMO file (command output file) is assigned. It contains all the information of the summary file as well as some additional information like the flux depression factor, the dose rates at various stages of shielding thicknesses, the details (energy and % yield) of various radioactive gammas etc. This part of output may be of interest for the detailed analysis of the PIR.

A sample output is given in Appendix-B.

4. ANALYSIS OF SOME MEAS RED IRRADIATIONS

We have analysed some irradiations carried out in CIRUS reactor using this code to check for its efficacy in predicting various entities.

4.1 Irradiation of Cobalt Sample in an Adjuster Tray Rod

Cobalt pellets packed in the form of an annular cylinder in CIRUS capsules were irradiated in all the 30 positions of the adjuster tray rod for isotope production. Each capsule contained 25 gms of cobalt and they were irradiated for 30509 MWD from 17.1.1980 to 12.9.1983 in Cirus reactor. Their activity was measured on 21.11.1983.

4.1.1 Radioactivities

The Co-60 activities of these capsules predicted by the code in the samples in different positions of the tray rod are given in Table-1. They are compared with the measured activities in the same table.

The reactor power and so also the neutron flux levels in different capsules can not remain constant over such a long period. The variations of the neutron flux can not be accounted exactly in the code; however a uniform average flux over the entire period is calculated based on the actual reactor power developed during the period. The intercomparison of the calculated and measured values of radioactivities in different capsules shows that the predictions are satisfactory, keeping in mind the uncertainties of the measurements. The activity of 1750 curies predicted by the code in the maximum flux position compares well with the measured 1700 curies. The total radioactivity predicted in the whole adjuster tray rod is 36219 curies which compares reasonably well with the measured value of 32984 curies.

4.1.2 Reactivity Load and Heating Rate

The reactivity load and heating rate predictions for cobalt capsules in different positions of the tray rod are given in Table 2. Although no measurements for heating in the individual capsules have been made, it is accepted [6] that a capsule of 30 gms of cobalt produces around 50 watts of power in the maximum flux position in tray rods in this reactor. The 25 gms cobalt should produce around 42 watts. The code predicts around 39 watts of power in the maximum flux position which is quite satisfactory in view of the complexity of its calculation.

The total reactivity load of the whole adjuster tray rod is predicted to be about 2.57 mk which is reasonably good from the operational experience of the reactor.

4.2 Irradiation of Antimony Samples

Activity produced in small samples of antimony powder irradiated in CIRUS was analysed [7] earlier in connection with the production of Sb-124 gamma sources for the start-up of Tarapur reactor. Antimony powder of mass 20 mg was sealed alongwith cobalt monitors of 13 mg in a normal aluminium capsule. Ten such capsules were irradiated in different tiers of an isotope tray rod of CIRUS reactor for 48 hours with an average power rating of 30 MW. Average flux seen by each capsule was estimated by measuring the Co-60 activity produced in cobalt monitors. These fluxes, in turn, were used to estimate the Sb-124 activity and compared with the measured values.

We have also analysed these measurements usin the present code. The predicted Sb-124 activities in different capsules are compared with the measurment values in Table-3. It may be mentioned that the effect of variations in reactor power, operating heavy water height and adjuster rod manipulations during irradiations is not accounted in the code. The actual fluxes seen by the sample are, therefore somewhat different from their representative values built in the code . The actual fluxes have, however, been evaluated by intercomparing the measured Co-60 activities of the monitors with those predicted by the code using the representative flux values. It can be seen from Table-3 that the calculated values of Sb-124 activity in various capsules agree reasonably well with the measured values.

4.3 Analysis of Miscellaneous Irradiations

Some of the samples irradiated in CIRUS tray rod and Self-Serve positions have been analysed [3] to check for the shielding requirement and dose rate predictions of the code. The samples were assumed to be spherical in geometry and the actual plant factor during irradiations and the cooling times (time elapsed between end of irradiation and dose rate measurement) were used in this analysis. The shielding requirements predicted by the code and the actual shielding used are given in Table 4. It may be seen that the predicted shield thicknesses to reduce the dose rate at 1 foot within the permissible limit of 200 mR/hr are the same as actually used for the purpose in all the cases. The dose rates at 1 foot calculated by the code for these samples with the lead shield provided are also compared with the measured values in the same table. It is seen that there are some differences between the dose rates calculated at 1 foot and the measured values. These discrepancies may, partly, be due to theapproximations used in the calculations, the uncertainties in the radiation data or due to the presence of some trace elements in the samples. It may be mentioned that the dose rates are strongly (inverse square) dependent on the distance between the source and the point of measurement. The predicted dose rates are at a point exactly at 1 foot from the source whereas these operational measurements are made just to ensure that the dose rates do not exceed the permissible limits. It is quite lilely that the operational measurements of dose rates may not be exactly at 1 foot (the measured value could be indicative) The intercomparison of the calculated and measured radioactivity productions in other samples, as given in tables 1 and 3, is found to be quite satisfactory. In view of the uncertainties involved in the operational measurements of the dose rates at 1 foot, the dose rate predictions by the code appear to be satisfactory. The sheilding requirements, however, are correctly predicted in all the cases.

5. *CONCLUSION*

A program SHARDA has been developed for Sample Heat, Activity, Reactivity and Dose Analysis of Pile Irradiation Request (PIR) in CIRUS reactor. The code will enable to get rid of the monotony in routine desk calculations performed hitherto for such evaluations. The evaluation by the code will eliminate the possible human errors in collecting various input data required for the purpose, such as isotopic compositions of various isotopes in the costituent elements of the sample, their various nuclear cross-sections, their radiation characteristics (half life, energy and percentage of the emanating gammas) of different activities produced during irradiation and the irradiating flux values assigned to various irradiating locations in the reactor. All these data for different elements and the representative neutron fluxes in all possible irradiating positions have been built in the code and only a bare minimum input (required to specify the sample details) is needed to carry out these evaluations. Evaluations using the code will further eliminate the calculational errors possible with a desk calculator. A summary of output alongwith input for a PIR is printed on a single page output which can be filed with ease for records.

The code takes into account the target and product depletion effects during irradiation which are normally ignored in hand calculations. These effects could be significant for long or high flux irradiations. The efficacy of the code in estimating the parameters of interest for a PIR evaluation has been tested against a variety of measurments.

6. ACKNOWLEDGEMENTS

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7. REFERENCES:

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2. R.G. Jaeger etal: "Engineering Compendium on Radiation Shielding" Vol I - Shielding Fundamentals and Methods (1968).

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5. R.H. Krishnan: Private Communication from Isotope Division, B.A.R.C.,Bombay (1984).

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TABLE NO: 1

CO-60 ACTIVITIES IN CAPSULES IRRADIATED IN DIFFERENT TIERS OF ADJUSTER TRAY ROD IN CIRUS REACTOR

POSITION IN TRAY ROD (FROM BOTTOM)	MEASURED ACTIVITY (CURIES)	CALCULATED ACTIVITY (CURIES)
1	530	611
2	595	736
3	850	914
4	935	1030
5	1115	1180
6	1230	1280
7	1305	1400
8	1445	1480
9	1455	1570
10	1500	1620
11	1625	1690
12	1700	1710
13	1700	1740
14	1700	1750
15	1700	1740
16	1615	1720
17	1570	1670
18	1465	1630
19	1400	1550
20	1380	1480
21	1220	1370
22	1115	1280
23	956	1140
24	870	1030
25	670	865
26	510	746
27	340	557
28	235	425
29	148	222
30	105	83
TOTAL:	32984	36219

TABLE NO: 2

. REACTIVITY LOAD AND HEATING RATE PREDICTIONS FOR COBALT CAPSULES IRRADIATED IN DIFFERENT TIERS OF ADJUSTER TRAY ROD IN CIRUS REACTOR

POSITION IN TRAY ROD (FROM BOTTOM)	REACTIVITY LOAD (MK)	HEATING RATE (W)
1	0.018	16.1
2	0.026	18.5
3	0.041	22.0
4	0.052	24.2
5	0.069	27.3
6	0.081	29.2
7	0.099	31.8
8	0.110	33.3
9	0.126	35.3
10	0.135	36.4
11	0.146	37.7
12	0.151	38.3
13	0.156	38.8
14	0.157	38.9
15	0.155	38.7
16	0.151	38.3
17	0.143	37.4
18	0.135	36.5
19	0.122	34.8
20	0.111	33.4
21	0.094	31.1
22	0.082	29.4
23	0.064	26.5
24	0.053	24.4
25	0.037	21.0
26	0.027	18.7
27	0.015	15.0
28	0.0086	12.4
29	0.0023	8.5
30	0.0003	5.9
TOTAL:	2.5672	839.8

TABLE NO: 3

COMPARISON OF CALCULATED AND MEASURED SB-124 ACTIVITIES FOR 20 MG ANTIMONY SAMPLES IRRADIATED IN DIFFERENT TIERS OF A TRAY ROD IN CIRUS

PIR NO.	CO-60 MONITOR ACTIVITY(MC)		FLUX CORECTION FACTOR	SB-124 SAMPLE ACTIVITY(MC)	
	CAL.	MEAS.		*CAL.	MEAS.
3342	3.80	4.65	1.22	5.5	6.1
3343	4.01	4.90	1.22	5.7	5.9
3344	4.17	4.97	1.19	5.8	5.8
3345	4.24	4.97	1.17	5.8	5.9
3346	3.63	4.45	1.22	5.2	5.4
3347	4.33	4.92	1.14	5.7	6.0
3348	4.30	4.60	1.07	5.3	5.6
3349	4.25	4.57	1.07	5.3	5.1
3350	4.13	4.15	1.00	4.8	5.1
3351	3.81	3.45	0.90	4.0	4.1

*CALCULATED VALUES INCLUDE THE FLUX CORRECTION FACTORS DETERMINED BY COBALT MONITORS.

TABLE NO: 4

COMPARISON OF CALCULATED AND MEASURED DOSE RATES AND SHIELD REQUIREMENTS

FOR MISCELLANEOUS SAMPLES IRRADIATED IN CIRUS

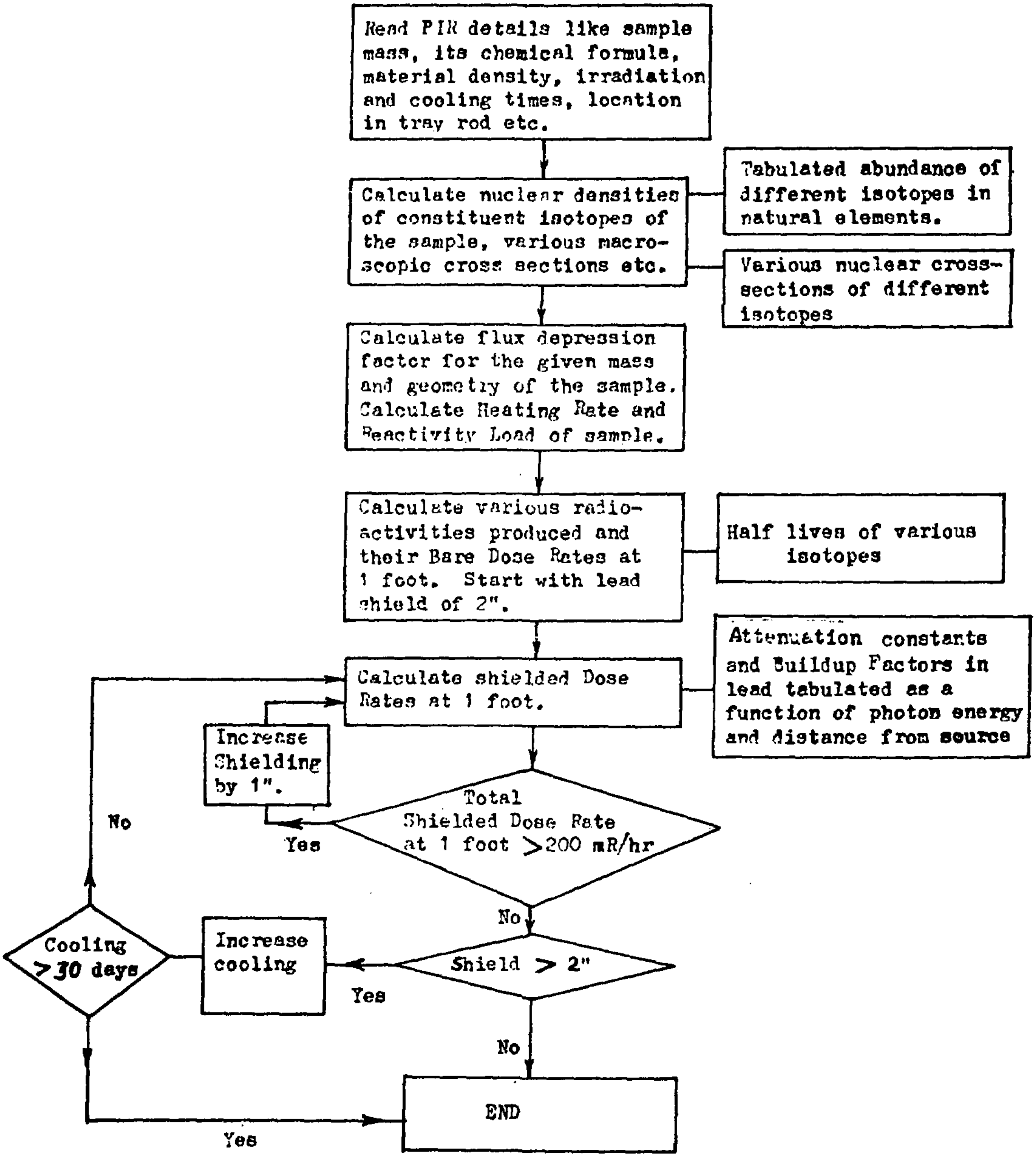
PIR NO.	MATERIAL	MASS (GM)	FLUX ($X10^{13}$)	IRRADIATION (MWD)	COOLING (HRS)	LEAD SHIELD (INCHES)		SHIELDED DOSE RATE AT 1 FOOT(MR/HR)	
						CAL.	MEAS.	CAL.	MEAS.
8332	$BACO_3$	7.0	4.69 (TR)	15144.0	1.0	3	3	140	100
9343	NI	10.0	5.55 (TR)	4918.0	0.8	3	3	99	170
9687	ND_2O_3	0.125	4.90 (TR)	642.0	24.0	2	2	33	40
9717	HGO	4.4	1.4 (SS)	75.2	2.0	2	2	25	100
9748	NH_4BR	0.05	1.01 (SS)	45.5	5.0	2	2	42	180
9805	$MNSO_4$	0.01	0.30 (SS)	7.5	0.8	2	2	18	100

TR = TRAY ROD

SS = SELF SERVE

FIGURE - 1

LOGICAL FLOW DIAGRAM



APPENDIX - A

INPUT FILE

```
C01
999 25.0 8.9 32016.0 1680.0 14 4 1 0.572
0.54 0.60 4.0
8A1C 10 3
8332 7.0 4.43 -15144.0 0.0 20 8 0 0.58
```

APPENDIX - B

OUTPUT FILES

B.1 SUMMARY FILE

PIR NO= 999 C01

MASS(GM) (+COM/-MIX)	DEN(GM/CC)	IRRADIATION (+HR/-MWD)	COOL(HR)	P.F.	LOCATION (+TR/-SS)	CIRCLE	GEOM	ROUT(CM)	RIN(CM)	HEIGHT(CM)
25.00000	8.900	0.320D 05	0.168D 04	0.572	14	4	1	0.94	0.60	4.00

FLUX DEPRESSION FACTOR= 0.552

TOTAL HEATING RATE(WATTS)= 38.581

SAMPLE REACTIVITY LOAD(MK) = 0.1591

FOR BARE IRRADIATED SAMPLE

ISOTOPE	HALFLIFE(HRS)	CURIES	DOSE RATE(MR/HR)AT 1 FOOT
CO- 60	0.174D 00	0.103D-98	0.348D-96
CO- 60	0.462D 05	0.175D 04	0.262D 08

TOTAL(SAMPLE+CAPSULE) BARE DOSE RATE(MR/HR)AT 1 FT= 0.262D 08

SHIELDING REQUIREMENTS ARE

COOLING TIME(HRS)	SHIELD(INCH)	D.R.(MR/HR) AT 1 FOOT	D.R. FOR MAX4
1680.00	9.00	54.3	54.3

PIR NO=8332 BA1C 10 3

MASS(GM) (+COM/-MIX)	DEN(GM/CC)	IRRADIATION (+HR/-MWD)	COOL(HR)	P.F.	LOCATION (+TR/-SS)	CIRCLE	GEOM
7.00000	4.430	-0.151D 05	0.000D 00	0.580	20	8	0

FLUX DEPRESSION FACTOR= 0.998

TOTAL HEATING RATE(WATTS)= 4.161

SAMPLE REACTIVITY LOAD(MK) = 0.0028

FOR BARE IRRADIATED SAMPLE

ISOTOPE	HALFLIFE(HRS)	CURIES	DOSE RATE(MR/HR)AT 1 FOOT
BA-131	0.250D 00	0.401D-01	0.261D 02
BA-131	0.281D 03	0.217D 00	0.666D 03
BA-139	0.138D 01	0.426D 01	0.105D 05
C - 14	0.502D 08	0.177D-07	0.000D 00
O - 19	0.750D-02	0.146D-04	0.119D 00

TOTAL(SAMPLE+CAPSULE) BARE DOSE RATE(MR/HR)AT 1 FT= 0.1184D 05

SHIELDING REQUIREMENTS ARE

COOLING TIME(HRS)	SHIELD(INCH)	D.R.(MR/HR) AT 1 FOOT	D.R. FOR MAX4
0.00	4.00	56.1	77.2
1.00	3.00	140.0	192.6
2.00	3.00	95.1	130.8
4.00	2.00	167.4	230.3

B.2 DETAILED FILE(APPEARS ON TERMINAL,CAN ALSO BE STORED)

```
                        PIR NO= 999          THE SAMPLE IS C01

  MASS IN GRAMS                  =   0.2500D 02

  DENSITY (GMS/CC)               =   0.8900D 01

  IRRADIATION TIME(+HRS/-MWD)  =   0.3202D 05

  COOLING TIME(HRS)              =   0.1680D 04

  PLANT FACTOR                   =   0.5720D 00

  T.R.TIER NO.(+)/S.S.NO.(-)  =     14

  CIRCLE NUMBER (FOR T.R.)      =      4

  GEOMETRY (0/1  SPH/CYL)       =      1

  MOLECULAR WEIGHT               =   0.5890D 02

  CYLINDRICAL GEOMETRY
                                   OUTER RADIUS(CM)  = 0.9400 00
                                   INNER RADIUS(CM)  = 0.6000 00
                                   HEIGHT (CM)       = 0.4000 01
                                   VOL OF  SAMPLE(CC)= 0.6580 01
                                   FLUX  DEPRESSION  FACTOR(CYL)= 0.5520 00

                                         *****CORE GAMMA HEAT(WATTS)    =     6.933
                                         *****CAPTURE GAMMA HEAT(WATTS)=    31.647

                                         ***** TOTAL HEAT(WATTS)        =    38.581

                                  ***** SHIELD=   2.0 INCH *****

  FOR THE ELEMENT CO

      ISOTOPE CO- 60(HALF LIFE(HRS)=0.1740 00)
             ACTIVITY IN CURIES                      = 0.1000-98
                GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.3480-96,SHIELDED DOSE RATE=0.1000-98
             BARE DOSE RATE(MR/HR) AT 1 FOOT    = 0.3480-96
             SHIELDED DOSE RATE(MR/HR) AT 1FOOT= 0.1000-98

      ISOTOPE CO- 60(HALF LIFE(HRS)=0.4620 05)
             ACTIVITY IN CURIES                      = 0.1750 04
                GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.1230 08,SHIELDED DOSE RATE=0.7970 06
                GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.1390 08,SHIELDED DOSE RATE=0.1200 07
             BARE DOSE RATE(MR/HR) AT 1 FOOT    = 0.2620 08
             SHIELDED DOSE RATE(MR/HR) AT 1FOOT= 0.1990 07
  FOR CAPSULE

      NA-24 ACTIVITY (CURIES)      = 0.5210-34
      NA-24 BARE DOSE RATE (MR/HR) AT 1 FOOT= 0.1770-30
      NA-24 SHIELDED DOSE RATE (MR/HR) AT 1 FOOT= 0.2410-31

                                        ******TOTAL SAMPLE REACTIVITY LOAD(MK)=      0.1591

                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.1990 07
```

```
                              ***** SHIELD=   3.0 INCH *****

FOR THE ELEMENT CO
------------------
                    GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.348D-96,SHIELDED DOSE RATE=0.100D-98
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.123D 08,SHIELDED DOSE RATE=0.171D 06
                    GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.139D 08,SHIELDED DOSE RATE=0.304D 06
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.475D 06
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.475D 06
                                            ------------------------------------------------------

                              ***** SHIELD=   4.0 INCH *****

FOR THE ELEMENT CO
------------------
                    GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.348D-96,SHIELDED DOSE RATE=0.100D-98
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.123D 08,SHIELDED DOSE RATE=0.350D 05
                    GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.139D 08,SHIELDED DOSE RATE=0.721D 05
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.107D 06
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.107D 06
                                            ------------------------------------------------------

                              ***** SHIELD=   5.0 INCH *****

FOR THE ELEMENT CO
------------------
                    GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.348D-96,SHIELDED DOSE RATE=0.100D-98
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.123D 08,SHIELDED DOSE RATE=0.709D 04
                    GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.139D 08,SHIELDED DOSE RATE=0.174D 05
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.245D 05
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.245D 05
                                            ------------------------------------------------------

                              ***** SHIELD=   6.0 INCH *****

FOR THE ELEMENT CO
------------------
                    GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.348D-96,SHIELDED DOSE RATE=0.100D-98
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.123D 08,SHIELDED DOSE RATE=0.141D 04
                    GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.139D 08,SHIELDED DOSE RATE=0.395D 04
   CO- [illegible] SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.536D 04
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT [illegible] .536D 04
                                            ------------------------------------------------------

                              ***** SHIELD=   7.0 INCH *****

FOR THE ELEMENT CO
------------------
                    GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.348D-96,SHIELDED DOSE RATE=0.100D-98
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.123D 08,SHIELDED DOSE RATE=0.269D 03
                    GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.139D 08,SHIELDED DOSE RATE=0.915D 03
   CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.118D 04
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.118D 04
                                            ------------------------------------------------------
```

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***** SHIELD=   6.0 INCH *****

FOR THE ELEMENT CO
-----------------
                   GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.348D-96,SHIELDED DOSE RATE=0.100D-98
  CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                   GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.123D 08,SHIELDED DOSE RATE=0.511D 02
                   GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.139D 08,SHIELDED DOSE RATE=0.202D 03
  CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.253D 03
                                     SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.253D 03
                                     ----------------------------------------------------------

***** SHIELD=   9.0 INCH *****

FOR THE ELEMENT CO
-----------------
                   GAMMA(MEV)=0.058,% YIELD=100.00,BARE DOSE RATE=0.348D-96,SHIELDED DOSE RATE=0.100D-98
  CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                   GAMMA(MEV)=1.170,% YIELD=100.00,BARE DOSE RATE=0.123D 08,SHIELDED DOSE RATE=0.993D 01
                   GAMMA(MEV)=1.330,% YIELD=100.00,BARE DOSE RATE=0.139D 08,SHIELDED DOSE RATE=0.444D 02
  CO- 60 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.543D 02
                                     SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.543D 02
                                     ----------------------------------------------------------

                    PIR NO=8332        THE SAMPLE IS BA1C 10 3

MASS IN GRAMS                  =   0.70000 01

DENSITY (GMS/CC)               =   0.44300 01

IRRADIATION TIME(+HRS/-MWD)    =  -0.15140 05

COOLING TIME(HRS)              =   0.00000 00

PLANT FACTOR                   =   0.58000 00

T.R.TIER NO.(+)/S.S.NO.(-)     =    20

CIRCLE NUMBER (FOR T.R.)       =     8

GEOMETRY (0/1  SPH/CYL)        =     0

MOLECULAR WEIGHT               =   0.19730 03

FLUX  DEPRESSION FACTOR(SPHERICAL)   =     0.998

                                     *****CORE GAMMA HEAT(WATTS)    =     3.813
                                     *****CAPTURE GAMMA HEAT(WATTS)=     0.348

                                     ***** TOTAL HEAT(WATTS)        =     4.161
                                        ------------------------------------

***** SHIELD=   2.0 INCH *****

FOR THE ELEMENT BA
-----------------

    ISOTOPE BA-131(HALF LIFE(HRS)=0.250D 00)
           ACTIVITY IN CURIES                  = 0.401D-01
              GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.261D 02,SHIELDED DOSE RATE=0.100D-98
           BARE DOSE RATE(MR/HR) AT 1 FOOT    = 0.261D 02
           SHIELDED DOSE RATE(MR/HR) AT 1FOOT= 0.100D-98
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ISOTOPE BA-131(HALF LIFE(HRS)=0.281D 03)
          ACTIVITY IN CURIES                    = 0.217D 00
              GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.388D 02,SHIELDED DOSE RATE=0.182D 01
              GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.597D 02,SHIELDED DOSE RATE=0.111D 01
              GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.513D 03,SHIELDED DOSE RATE=0.220D 00
              GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.548D 02,SHIELDED DOSE RATE=0.773D-14
          BARE DOSE RATE(MR/HR) AT 1 FOOT       = 0.666D 03
          SHIELDED DOSE RATE(MR/HR) AT 1FOOT= 0.316D 01

ISOTOPE BA-139(HALF LIFE(HRS)=0.138D 01)
          ACTIVITY IN CURIES                    = 0.426D 01
              GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.695D 04,SHIELDED DOSE RATE=0.671D 03
              GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.354D 04,SHIELDED DOSE RATE=0.173D-35
          BARE DOSE RATE(MR/HR) AT 1 FOOT       = 0.105D 05
          SHIELDED DOSE RATE(MR/HR) AT 1FOOT= 0.671D 03
FOR THE ELEMENT C
-----------------

ISOTOPE C - 14(HALF LIFE(HRS)=0.502D 08)
          ACTIVITY IN CURIES                    = 0.177D-07
          BARE DOSE RATE(MR/HR) AT 1 FOOT       = 0.000D 00
          SHIELDED DOSE RATE(MR/HR) AT 1FOOT= 0.000D 00
FOR THE ELEMENT O
-----------------

ISOTOPE O - 19(HALF LIFE(HRS)=0.750D-02)
          ACTIVITY IN CURIES                    = 0.146D-04
              GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.119D 00,SHIELDED DOSE RATE=0.105D-01
          BARE DOSE RATE(MR/HR) AT 1 FOOT       = 0.119D 00
          SHIELDED DOSE RATE(MR/HR) AT 1FOOT= 0.105D-01
FOR CAPSULE
-----------
     NA-24 ACTIVITY (CURIES)        = 0.193D 00
     NA-24 BARE DOSE RATE (MR/HR) AT 1 FOOT= 0.656D 03
     NA-24 SHIELDED DOSE RATE (MR/HR) AT 1 FOOT= 0.894D 02

                                        ******TOTAL SAMPLE REACTIVITY LOAD(MK)=      0.0028
                                        ---------------------------------------------
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.763D 03
                                        ---------------------------------------------

                              ***** SHIELD=   3.0 INCH *****

FOR THE ELEMENT BA
------------------
                   GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.261D 02,SHIELDED DOSE RATE=0.100D-98
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                   GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.388D 02,SHIELDED DOSE RATE=0.324D 00
                   GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.597D 02,SHIELDED DOSE RATE=0.130D 00
                   GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.513D 03,SHIELDED DOSE RATE=0.361D-02
                   GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.548D 02,SHIELDED DOSE RATE=0.582D-22
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.458D 00
                   GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.695D 04,SHIELDED DOSE RATE=0.183D 03
                   GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.354D 04,SHIELDED DOSE RATE=0.231D-55
   BA-139 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.183D 03
FOR THE ELEMENT C
-----------------
   C - 14 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.000D 00
FOR THE ELEMENT O
-----------------
                   GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.119D 00,SHIELDED DOSE RATE=0.272D-02
   O - 19 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.272D-02
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.214D 03
                                        ---------------------------------------------
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                                   ***** SHIELD=   4.0 INCH *****

FOR THE ELEMENT BA
-----------------
                    GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.261D 02,SHIELDED DOSE RATE=0.100D-98
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.388D 02,SHIELDED DOSE RATE=0.556D-01
                    GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.597D 02,SHIELDED DOSE RATE=0.132D-01
                    GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.513D 03,SHIELDED DOSE RATE=0.554D-04
                    GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.546D 02,SHIELDED DOSE RATE=0.434D-30
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.688D-01
                    GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.695D 04,SHIELDED DOSE RATE=0.461D 02
                    GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.354D 04,SHIELDED DOSE RATE=0.300D-75
   BA-139 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.461D 02
FOR THE ELEMENT C
-----------------
   C - 14 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.000D 00
FOR THE ELEMENT O
-----------------
                    GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.119D 00,SHIELDED DOSE RATE=0.656D-03
   O - 19 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.656D-03
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.561D 02
                                        ------------------------------------------------------------

                                        ***** COOLING TIME (HRS) =   1.0 *****

                                   ***** SHIELD=   2.0 INCH *****

FOR THE ELEMENT BA
-----------------
                    GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.163D 01,SHIELDED DOSE RATE=0.100D-98
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.387D 02,SHIELDED DOSE RATE=0.182D 01
                    GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.595D 02,SHIELDED DOSE RATE=0.111D 01
                    GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.511D 03,SHIELDED DOSE RATE=0.219D 00
                    GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.546D 02,SHIELDED DOSE RATE=0.771D-14
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.315D 01
                    GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.423D 04,SHIELDED DOSE RATE=0.406D 03
                    GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.214D 04,SHIELDED DOSE RATE=0.165D-35
   BA-139 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.406D 03
FOR THE ELEMENT C
-----------------
   C - 14 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.000D 00
FOR THE ELEMENT O
-----------------
                    GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.881D-41,SHIELDED DOSE RATE=0.781D-42
   O - 19 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.781D-42
                                        SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.494D 03
                                        ------------------------------------------------------------

                                   ***** SHIELD=   3.0 INCH *****

FOR THE ELEMENT BA
-----------------
                    GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.163D 01,SHIELDED DOSE RATE=0.100D-98
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.387D 02,SHIELDED DOSE RATE=0.323D 00
                    GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.595D 02,SHIELDED DOSE RATE=0.130D 00
                    GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.511D 03,SHIELDED DOSE RATE=0.361D-02
                    GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.546D 02,SHIELDED DOSE RATE=0.580D-22
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.457D 00
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                    GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.420D 04,SHIELDED DOSE RATE=0.111D 03
                    GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.214D 04,SHIELDED DOSE RATE=0.140D-55
   BA-139 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.111D 03

FOR THE ELEMENT C
-----------------
   C - 14 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.000D 00
FOR THE ELEMENT O
-----------------
                    GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.881D-41,SHIELDED DOSE RATE=0.202D-42
   O - 19 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.202D-42
                                    SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.140D 03
                                         -------------------------------------------------------

                                     ***** COOLING TIME (HRS) =   2.0 *****

                              ***** SHIELD=   2.0 INCH *****

FOR THE ELEMENT BA
-----------------
                    GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.102D 00,SHIELDED DOSE RATE=0.100D-98
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.386D 02,SHIELDED DOSE RATE=0.181D 01
                    GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.594D 02,SHIELDED DOSE RATE=0.111D 01
                    GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.513D 03,SHIELDED DOSE RATE=0.219D 00
                    GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.545D 02,SHIELDED DOSE RATE=0.769D-14
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.314D 01
                    GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.254D 04,SHIELDED DOSE RATE=0.246D 03
                    GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.130D 04,SHIELDED DOSE RATE=0.633D-36
   BA-139 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.246D 03
FOR THE ELEMENT C
-----------------
   C - 14 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.000D 00
FOR THE ELEMENT O
-----------------
                    GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.655D-81,SHIELDED DOSE RATE=0.581D-82
   O - 19 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.581D-82
                                    SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.330D 03
                                         -------------------------------------------------------

                              ***** SHIELD=   3.0 INCH *****

FOR THE ELEMENT BA
-----------------
                    GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.102D 00,SHIELDED DOSE RATE=0.100D-98
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                    GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.386D 02,SHIELDED DOSE RATE=0.322D 00
                    GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.594D 02,SHIELDED DOSE RATE=0.130D 00
                    GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.510D 03,SHIELDED DOSE RATE=0.360D-02
                    GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.545D 02,SHIELDED DOSE RATE=0.579D-22
   BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.456D 00
                    GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.254D 04,SHIELDED DOSE RATE=0.669D 02
                    GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.130D 04,SHIELDED DOSE RATE=0.845D-56
   BA-139 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.669D 02
FOR THE ELEMENT C
-----------------
   C - 14 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.000D 00
FOR THE ELEMENT D
-----------------
                    GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.655D-81,SHIELDED DOSE RATE=0.150D-82
   O - 19 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.150D-82
                                    SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.951D 02
                                         -------------------------------------------------------
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                                   ***** COOLING TIME (HRS) =    4.0 *****

                             ***** SHIELD=   2.0 INCH *****

FOR THE ELEMENT BA
------------------
                   GAMMA(MEV)=0.108,% YIELD=100.00,BARE DOSE RATE=0.399D-03,SHIELDED DOSE RATE=0.100D-98
  BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.100D-98
                   GAMMA(MEV)=1.030,% YIELD=  2.90,BARE DOSE RATE=0.384D 02,SHIELDED DOSE RATE=0.180D 01
                   GAMMA(MEV)=0.820,% YIELD=  5.60,BARE DOSE RATE=0.591D 02,SHIELDED DOSE RATE=0.110D 01
                   GAMMA(MEV)=0.495,% YIELD= 79.70,BARE DOSE RATE=0.508D 03,SHIELDED DOSE RATE=0.218D 00
                   GAMMA(MEV)=0.245,% YIELD= 17.20,BARE DOSE RATE=0.542D 02,SHIELDED DOSE RATE=0.765D-14
  BA-131 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.312D 01
                   GAMMA(MEV)=1.430,% YIELD= 19.00,BARE DOSE RATE=0.932D 03,SHIELDED DOSE RATE=0.960D 02
                   GAMMA(MEV)=0.163,% YIELD= 85.00,BARE DOSE RATE=0.475D 03,SHIELDED DOSE RATE=0.232D-36
  BA-139 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.900D 02
FOR THE ELEMENT C
------------------
  C - 14 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.000D 00
FOR THE ELEMENT D
------------------
                   GAMMA(MEV)=1.357,% YIELD=100.00,BARE DOSE RATE=0.814D-95,SHIELDED DOSE RATE=0.722D-96
  D - 19 SHIELDED DOSE RATE(MR/HR)AT 1 FOOT= 0.722D-96
                                 SHIELDED (SAMPLE+CAPSULE) DOSE RATE(MR/HR)AT 1 FOOT= 0.167D 03
                                    ----------------------------------------------------

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OK, COMO -E
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