ESTIMATING MAINTENANCE DOSE AT A MESON FACTORY

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ABSTRACT

By far the largest fraction of the dose to personnel at TRIUMF is due to work done in areas of high residual radiation fields. In order to be able to plan such work effectively in accordance with the ALARA principle it is necessary to be able to predict the induced fields for a variety of operating conditions followed by arbitrary cooling periods. We have measured the gamma-ray spectra at various locations in the cyclotron, the cyclotron vault, the beam lines and near associated meson production target stations using a small high purity germanium detector. Analysis of these spectra and a knowledge of the operating fields which induce this activity allows us to calculate the yields of the radioactive species induced by an arbitrary set of operating conditions. These yields in turn allow a good estimate of future induced fields to be made. By folding in data on man-hour requirements to meet maintenance schedules and planned future development work it is possible to project dose loads in light of higher beam production scenarios. We can thus identify areas or devices that need improvement in reliability or remote handling capability. Several such problem areas have been identified and corrective action taken to lower the man-dose during repair or maintenance of critical components. The estimates of future dose-loads are reviewed periodically as better measurements of radiation fields and statistics on maintenance and repair become available.

INTRODUCTION

At TRIUMF intense beams of 500 MeV protons extracted from the cyclotron are used to produce secondary beams of mesons for nuclear physics research. The primary radiological problem at TRIUMF is the relatively high (by accelerator standards) residual field encountered during the maintenance and repair of the cyclotron structures and associated beam lines and production target stations. Exposure rates shortly after shutdown range from 1 to 1000 mGy hr^{-1} and decay by one to two orders of magnitude during maintenance periods lasting up to two months. It is TRIUMF policy to try and limit the annual dose to any individual staff member to 10 mSv and at the same time to minimize the total man-dose to the staff. In order to comply with this policy we have developed a procedure for predicting maintenance and repair doses based on field measurements and analysis of maintenance and development requirements. Figure 1 shows a flow diagram outlining the method. From in situ measurements of gamma-ray spectra and exposure rates and the operating field history we are able to calculate the radionuclide production rates at a number of field points. Once the production rates are known the exposure rates are calculated for an arbitrary operating scenario. The exposure rates at the measurement points are then used to scale more extensive detailed residual radiation surveys in order to estimate future dose from the maintenance schedules. If these estimates conflict with our guidelines for limiting individual and collective dose we can study the effect of improved procedures and reliability of components or the effect of changes in the operating schedules in order to minimize these conflicts.

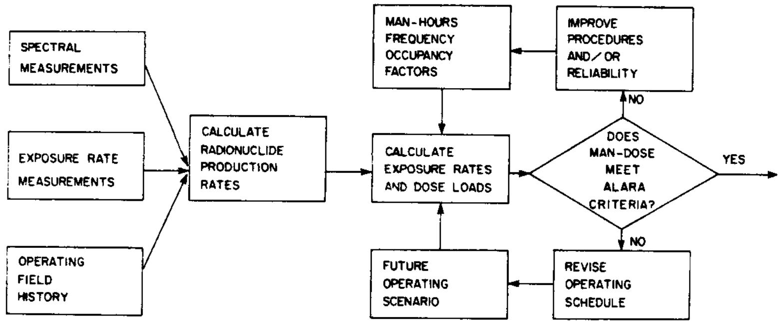

Fig. 1. Flow diagram illustrating dose planning procedure.

1. THE FIELD MEASUREMENTS

a) Induced Fields

The distribution of long-lived radionuclides induced in the accelerator structures were measured at eleven locations with a pure Ge detector having a detection efficiency of 0.48% relative to a (76.2 × 76.2 mm) NaI(TL) scintillator. A detector of such low sensitivity was chosen so that it could be operated in fields up to 1 mGy/h without appreciable counting losses. At the time of the measurement the accelerator had been shut down for 5 weeks. Measurements of the exposure rate at each location were made simultaneously using a portable G-M survey meter. Because of the small size of the Ge detector and the complex source distributions involved all geometry effects were neglected. The amount of a given radionuclide measured at a given location was calculated as an equivalent source at 25 cm using the measured efficiency of the Ge detector. The partial exposure rates due to the identified radionuclides were then calculated from the known decay schemes[1] and the sums normalized to the G-M survey meter measurements.

The most common materials present in the irradiated surroundings are concrete, stainless steel, aluminium and iron although the composition varies from location to location. Despite this the distribution of radionuclides in the induced activity is remarkably similar at all locations measured. Figure 2 shows the average fractional composition of the induced activity for the more prominent radionuclides, the error bars indicating the rms spread in the measurements. The distribution is also similar to that found by other workers.[2] The ^{59}Fe and ^{60}Co activity was especially high in the basement of the cyclotron vault where the operating low energy neutron fields are known to be high and the measurement points are close to the large mass (~3000 tonnes) of the cyclotron magnet.

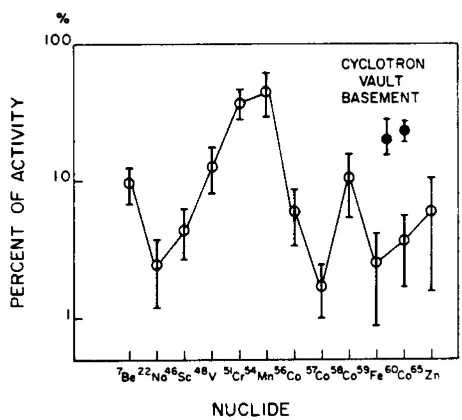

Fig. 2. Average distribution of radionuclids in the induced activity at TRIUMF.

The contribution of the short lived radionuclides was obtained from an analysis of the decay curves of the residual field as measured with TRIUMF beamspill monitors.[3] The contribution of ^{56}Mn at E.O.B. was approximately equal to the sum of the total exposure rate due to the long-lived components. In the cyclotron vault ^{24}Na contributed about 25% of the total.

b) Operating Fields

For most operating modes the ambient radiation fields are proportional to the extracted beam current. We therefore use the beam current as a measure of the operating fields. This procedure does not take into account variations in the fields due to mistuning of the cyclotron or beam lines but has the advantage of being the variable of direct interest in planning.

2. PREDICTION OF RESIDUAL FIELDS

From the measured distribution of radionuclides and the historical record of the operating fields as approximated by the beam current history we calculated the production rates for the various radionuclides using the data on half-lives in the literature.[1] These in turn allow us to calculate the residual fields for an arbitrary beam current scenario and decay period. In Fig. 3 the calculated long-lived component of the residual field at a typical location is compared to the measured values of the exposure rate. Differences between the measured and calculated values are thought to be due to beam tuning effects.

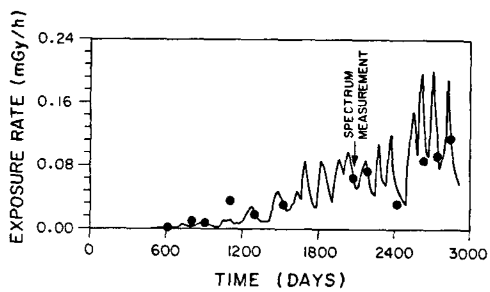

Fig. 3. Exposure rate in the cyclotron vacuum tank calculated from the beam current history. Points are measured values.

3. DOSE ESTIMATES

In order to estimate the dose which would be incurred during maintenance and repair in the active areas, the facility was divided into a number of subsystems. For each subsystem the most dose intensive tasks were identified and estimates of the frequency of maintenance and the number of man-hours per task were made by supervisors responsible for carrying out the task. In areas where there were large spatial gradients in the fields an occupancy factor was also estimated. 120 separate tasks were identified in this way and were categorized into those requiring a lengthy shutdown period (with a corresponding relief due to a long decay period) and those requiring a period of less than four days. The projected dose to personnel for each task was then calculated from the above data and detailed radiation surveys of the active areas. The frequency versus dose relationship for these tasks is shown in Fig. 4. Diagonal lines on this plot are lines of constant man-dose per year. The total man-dose predicted in this way for each of the first three years of the program was within 20% of that eventually incurred.

It became apparent that when the scaling of the residual fields as calculated for the intended future long term beam schedule were applied to these tasks those to the right of the 10 man-mSv yr^{-1} line could not be carried out after 1985 without severely compromising our dose guidelines.

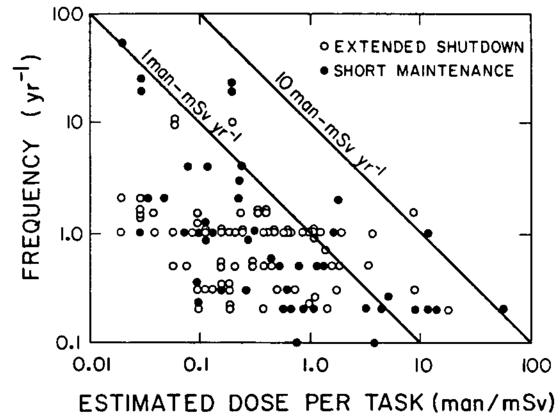

Fig. 4. Frequency vs Dose relationship for maintenance tasks.

4. PROGRAM FOR REDUCING DOSE

In order to close the loop implied in Fig. 1 a list of priorities for action was derived for the tasks above the 1 man-mSv yr^{-1} line in Fig. 4. The action taken to reduce the projected dose was of five types:

i) Make the device or system remotely handleable
ii) Redesign to reduce service requirements
iii) Redesign to eliminate the device or system
iv) Abandon the device if of limited use
v) Alter maintenance procedures, e.g. use local shielding.

Flexibility in scheduling beam was limited to shifting low intensity polarized beam periods to always occur before major planned shutdown periods to allow at least two weeks for 'cool down'. Regular maintenance periods of longer duration have been scheduled less frequently to allow at least the short-lived radioactivities to decay.

CONCLUSIONS

Estimates of exposure rates from the measured radionuclide distribution in the residual fields at TRIUMF have allowed us to make accurate predictions of the dose incurred during maintenance and development of the facility. These in turn have led to the redesign of procedures and equipment so that the total annual man-dose has levelled off despite the fact that the extracted beam current has continued to rise (Fig. 5).

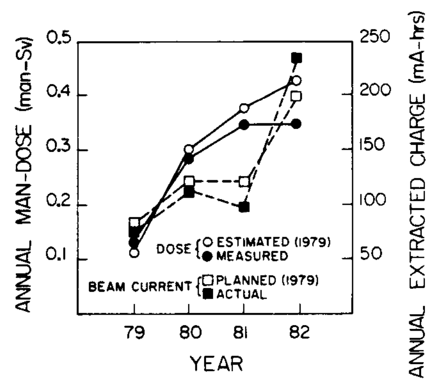

Fig. 5. Annual man-dose and extracted charge as a function of time.

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2. H. Hirayama et al., Measurements of Radionuclides Induced in the Accelerator Structure of the KEK-PS, Health Physics 43, 481 (1982)
3. J. Drozdoff et al., A Microprocessor-based Radiation Monitoring System, these proceedings.