# THE EFFECTIVENESS OF THE "HEAVY ION RADIATION CRITERION" AS AN INDEX OF ACCELERATOR RADIATION LEVELS



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L.H. Sprouse Jr. and D.J. Heppeler

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W. V. Lipton, C. A. Hunckler, G. A. Klochan, L. H. Sprouse Jr., and D. J. Heppeler (Occupational Health and Safety Division, Argonne National Laboratory, Argonne, IL 60439)

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The research program of the Physics Division's tandem Van de Graaff accelerator facility at Argonne National Laboratory often requires entries into a target room while the accelerator beam is present, both to perform adjustments on an experiment in progress and to set up a future experiment on another beam line. To assure the safety of personnel, while permitting the maximum feasible freedom of movement, it is useful to have a means of predicting the maximum possible radiation levels in the target room for the planned operating conditions. This would assure thorough radiation surveys, by Health Physics personnel, when they are needed, while minimizing delays for low hazard experiments.

Such a predictive index has been developed by John P. Schiffer, a Senior Physicist, at Argonne National Laboratory. It is called the "Heavy Ion Radiation Criterion" (HIRC), and is expressed as:

$$\mathrm{HIRC} = \frac{I\ X^3}{Q\ Z_p^2}\,(1 + 0.5A_p - Z_p)$$

where:

$$X = \begin{cases} (E - 3.7\ Z_p), & E - 3.7\ Z_p > 1 \\ 1, & E - 3.7\ Z_p \le 1 \end{cases}$$

where I is the shutter current, in electrical nanoamps, Q is the charge state of the beam, $Z_p$ and $A_p$ are the atomic number and atomic weight, respectively, of the beam particles, in integer amu, and E is the bombarding energy, in MeV.

The theoretical basis for the HIRC index is outside the scope of this presentation, but, roughly:

(1) X represents the beam particle energy above the reaction threshold, with $X^3/Z_p^2$ being a function of the cross section for nuclear reactions,

(2) I/Q is proportional to the number of beam particles per second,

(3) $(1 + 0.5\ A_p - Z_p)$ is a function of the neutron excess. This index is designed only for beam particles of $Z_p \geq 3$ and particle energies of less than 10 MeV per nucleon.

The authors have performed an empirical study of the effectiveness of the HIRC, as described, below. From July, 1978 to May, 1979, the actual, measured radiation levels for accelerator experiments were compared with the calculated HIRC values. For each experiment, the radiation level used was the maximum measured dose equivalent rate (gamma plus neutron), in mrem/h. Two problems were discovered:

(1) The HIRC index does not predict high radiation levels due to "soft x-rays," which would normally be absorbed by the beam line, but which may be present if the experimental apparatus includes thin windows.

(2) The HIRC index does not seem to apply to lithium beams, although more data is needed, here.

For experiments where these problems were not present, the

HIRC versus mrem/h points were plotted on log-log paper, as shown in figure 1. Three aspects of the HIRC-mrem/h relationship are evident from this plot:

(1) There seems to be a linear relationship between log (mrem/h) and log (HIRC).

(2) There is a wide dispersion of mrem/h readings for each HIRC value. This is probably due to the fact that the HIRC index predicts the maximum possible radiation level for a given set of conditions. This assumes that the beam impinges on a thick target of a material such as aluminum. Generally, this worst case situation does not exist, so the actual radiation levels are lower than the predicted maximum, accounting for the wide dispersion of data points.

(3) The HIRC seems to be useful for radiation protection purposes, since a low HIRC value assures that a low level of radiation is produced.

To confirm the linear relationship between log (mrem/h) and log (HIRC), the empirical correlation coefficient, r, was calculated for log (mrem/h) versus log (HIRC). This was found to have a value of 0.66, with 56 degrees of freedom, permitting us to reject the null hypothesis, that $r = 0$, with greater than 99% confidence.

The HIRC is used as part of a multistage, comprehensive radiation protection program, as described, below:

(1) Empirical safety determinations are made by accelerating a beam onto a thick aluminum target. This arrangement is designed to produce the maximum possible radiation levels for a given HIRC value.

(2) The radiation fields which are produced by this experiment are measured by the Health Physics Section. If no radiation fields (gamma plus neutron) greater than 10 mrem/h at 2 meters from an accelerator surface or 200 mrem/h at any accessible point are discovered, the HIRC value for this experiment is considered to be "safe." The highest "safe" value that we have measured is 21,100.

(3) If a proposed heavy ion experiment involves a HIRC value less than the highest "safe" value, then personnel may enter the target room before the Health Physics Section has performed a radiation survey. As a backup, to insure personnel safety, anyone entering the target room before a Health Physics survey has been completed must use survey instruments to determine that conditions are safe for entry.

(4) If a proposed experiment involves a projectile lighter than lithium or a HIRC value greater than one which is known to be "safe," then no entry into the target room is permitted until a Health Physics survey has been performed and shows that conditions are safe.

(5) To assure that all personnel radiation exposures are maintained at levels which are "As Low As Practicable" (ALAP), no integrated radiation exposures of greater than 20 mrem per week are permitted without a thorough risk versus benefit review. So far, no measured personnel radiation exposures have approached this level.

More data, especially from experiments at other accelerator facilities, would be useful in appraising the reliability of the

HIRC index. Also, further refinement of the index may be desirable. In its present form, however, the HIRC index, when used as part of a comprehensive radiation safety program at a small, heavy ion accelerator facility, has been found to be useful in permitting the maximum possible experimental freedom while assuring personnel safety.

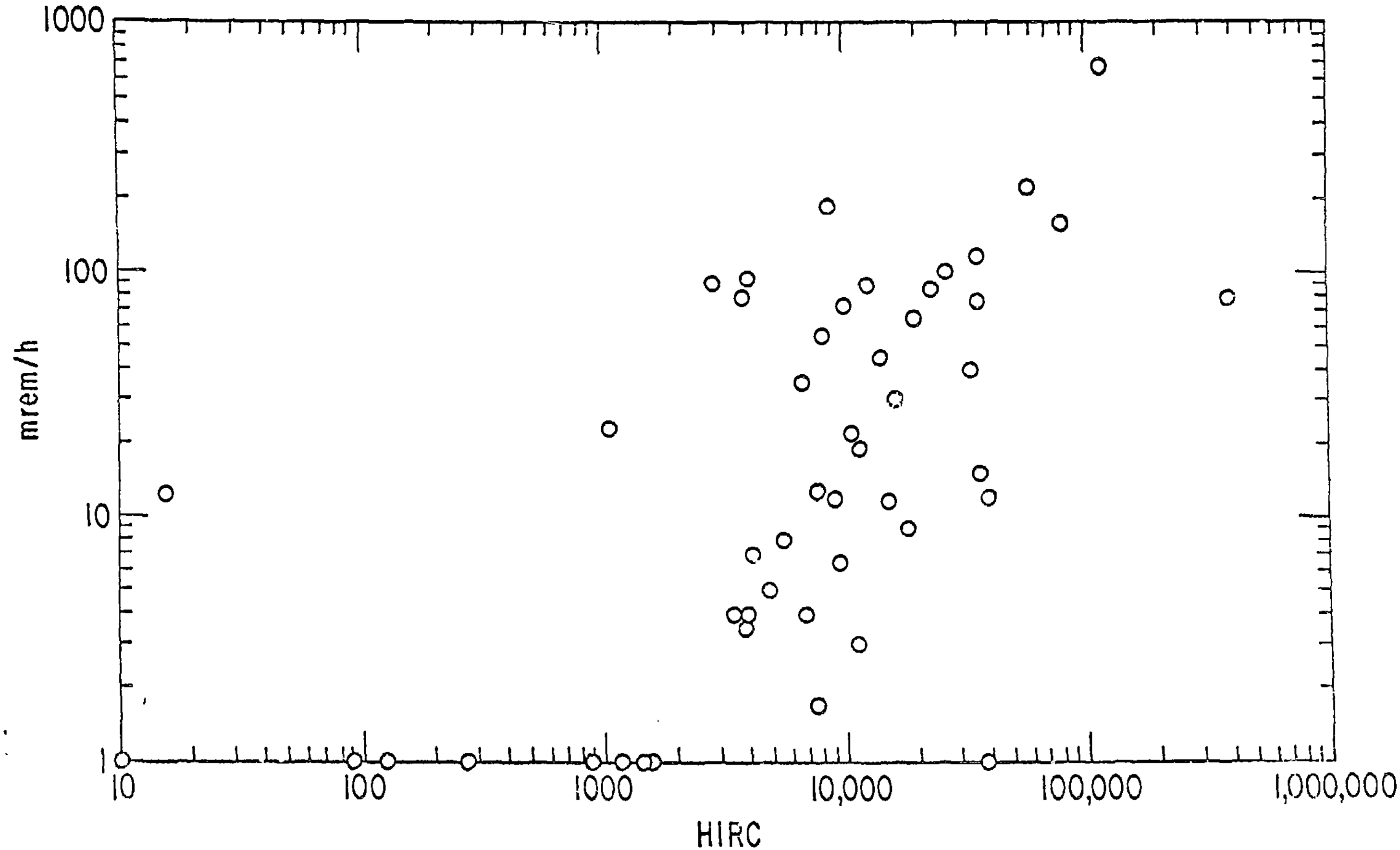


FIGURE 1 - HIRC VALUE VERSUS MEASURED RADIATION LEVEL