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PHOTON: A PROGRAM FOR SYNCHROTRON RADIATION DOSE CALCULATIONS

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Abstract

A computer program, PHOTON, has been developed to calculate radiation levels associated with a general synchrotron beamline arrangement. PHOTON calculates the transmitted and scattered spectra as the synchrotron beam passes through sequential filters. The Compton component of this scattered radiation can then be passed through a series of materials composing a shielding wall. This radiation can then be used to calculate a dose in a medium outside of the shielding wall. Program input is such that the sequence of operations is easily followed and modified for any beamline configuration.

Measurements have been performed by Elke Braüer on existing NSLS beamlines in various geometries. Good agreement between calculated and measured dose values was found in all cases. This agreement implies that results obtained for shielding of sources containing a wide range of energies, such as that of the NSLS High Field Superconducting Wiggler, are correct.

Introduction

Historically, the program FILTER [1] was used to calculate the spectral effects on synchrotron radiation from wiggler and bending magnet sources by "filters" composed of beamline elements. This program also calculated the power deposited in these filters and played a key role in the early design of the NSLS X-17 superconducting wiggler beamline in terms of power loading in the ring chamber and aperture - mask assemblies. Later in the development of the beamline, however, personnel safety issues made it necessary to address radiation problems associated with scattering of the intense high-energy wiggler beam by these same beamline elements.

As a consequence, the program PHOTON has evolved to include calculation of the scattering, attenuation by shield walls, and absorption by materials representative of the human body. This work has been two-fold: 1) to adapt the FILTER program, incorporating these changes; and 2) to compare calculations with experimental measurements on existing NSLS x-ray beamlines.

This paper is a description of the current state of the program and its capabilities. An experimental comparison has shown that the program consistently overestimates the level of scattering by a factor of 2-10. These results by Elke Braüer, et al. are described elsewhere in these proceedings [2].

Program Capabilities

Currently, the program will calculate the synchrotron spectrum from a dipole or wiggler type source in both energy and opening angle. A single electron dipole magnet source is assumed for the spectrum calculation. Allowance for multiple poles as in the case of a wiggler device is made by multiplying by the number of poles. No consideration is made for electron-photon beam interactions. finite source size, or horizontal photon beam distribution. This source distribution can then be sequentially passed through a set of filters. Here the name filters takes on a more general meaning, since they may be vertical apertures. windows. absorbers or scatterers. Filters can be used which are composed of a single element or a composite of elements. The parameters which define the element's absorption and scattering values are contained in separate input file. The absorption coefficients and scattering cross sections are calculated with a spline fitting algorithm using parameters from this input file.

After any filter, the following information can be written to an output file: the transmitted power as a function of energy and vertical opening distance: the vertically integrated transmitted spectrum; the total coherent and incoherent (Compton) scattered spectrum from the filter: the absorbed power as a function of the vertical opening distance; and the total absorbed power. If desired. there are plotting commands which will generate plots of the transmitted or scattered spectra through or from the filter.

Also, some medium may be placed immediately following a filter in order to calculate the dose in the filtered direct beam. This is useful, for example, in determining the effectiveness of photon shutters, backstops, etc.

Another useful aspect of the program is its capability to calculate the amount of Compton scattered radiation which will pass through a wall of arbitrary composition at some fixed angle to the direct beam. The scatterer is assumed to be an isotropic point source. This assumption overestimates the scattered intensities compared to that from an extended source. The total angularily integrated Compton cross section is used to calculate the scatter from a material in the incident spectrum. Also, the polarization dependence of the scattering is not accounted for. Ignoring these angular dependences will overestimate the scattered intensities in the horizontal plane while underestimating the scattered intensities in the vertical plane. Since these spectra are primarily used in the calculation of personnel doses from beamline component scatter, the overestimation of the scattered radiation in the horizontal plane builds in a margin of safety for shield wall design. In the vertical plane, the occupancy is assumed to be much less and scattered radiation may be considered less of a hazard. However, if this is not the case, one must be aware of the fact that the program will underestimate the level of scatter here.

This transmitted Compton scattered spectrum can then be used as a source for a dose calculation in some medium immediately outside the shielding wall. This is useful for assessing the effectiveness of shielding surrounding beamline components expected to generate large amounts of scattered radiation, such as monochromators, filters, apertures, etc.

The program's ability to predict dose levels from arbitrary beamline configurations makes it particularly powerful in assessing the overall safety of the beamline and the possible measures which can be taken to improve the shielding.

The Program Structure

The PHOTON program is written in FORTRAN and currently is being used on Digital Equipment Corp. VAX computers. The only non-standard feature of the program is its use of the graphics package MAPPER version 4.0 [3]. This feature can be modified since all plotting is done in subroutines. The advantage of the MAPPER graphics is that the plotting file created by PHOTON is ASCII and is editable to meet the needs of the user.

During the execution of the program the only user interaction is the input at the terminal the names of the input, output and plotting files to be used. The program can be logically broken into the following parts:

1) The incident synchrotron spectrum is calculated in both energy and opening angle based on the parameters obtained from the input file.

2) The elements used as filters or in composites are read from the input file and the mass absorption coefficients and scattering cross sections are calculated; the mass absorption coefficients and scattering cross sections of composites are then calculated.

3) The filter section is then entered, commands are read from the input file and calculations are done based upon the command. This is the final program section. Here the sequence of commands closely follows the sequence of beamline components which filter, scatter, or aperture

the incident synchrotron beam.

If the command is a:

a) Filter command The transmitted and absorbed power spectra are calculated for this filter, also the coherently and incoherently scattered spectra are calculated. The incoherent spectrum includes the Compton shift associated with it.

b) Plotting command The appropriate transmitted or scattered spectrum is sent to the plot file.

c) WALL command The inelastically scattered spectrum through a wall of elements or composites is calculated.

d) WHOM command The dose absorbed by some medium outside the previous shield wall is calculated.

e) NICK command The dose absorbed by some medium in the direct 'filtered' beam is calculated.

An Example

An example of the use of the program will be given in order to demonstrate its usefulness in determining beamline shielding requirements.

An input file was created which set parameters to simulate the maximum operating conditions of the X17 superconducting wiggler. With this input file, PHOTON calculated the following:

1) The original unfiltered synchrotron spectrum and the spectrum transmitted to the monochromator on the X17 beamline. Figure 1 shows the spectrum before the graphite filters and beryllium windows as the solid line.

The dashed line is the spectrum after 15.4 mils of graphite and 20 mils of beryllium windows.

2) The dose absorbed by the standard human tissue ICRU4 [4] in the direct beam near the 13 meter point of the beamline (See Table 1.).

3) The scatter from the silicon monochromator crystals.

4) The spectrum which was scattered through a tunnel shield wall composed of 1/4 inch steel and 1/4 inch lead. This spectrum is shown in figure 2. The notch in the spectrum is a result of the strong absorption at the K edge of lead.

5) The dose absorbed by the standard human tissue ICRU4 just outside of the shield wall (See Table 1.).

6) The spectrum which was scattered through a tunnel shield wall of zero thickness. This spectrum is shown in figure 3.

7) The dose absorbed by the standard human tissue ICRU4 in the absence of the shield wall (See Table 1.).

This type of calculation was performed to justify the current shielding required for the X17 beamline and resulted in the dose values shown in Table 1.

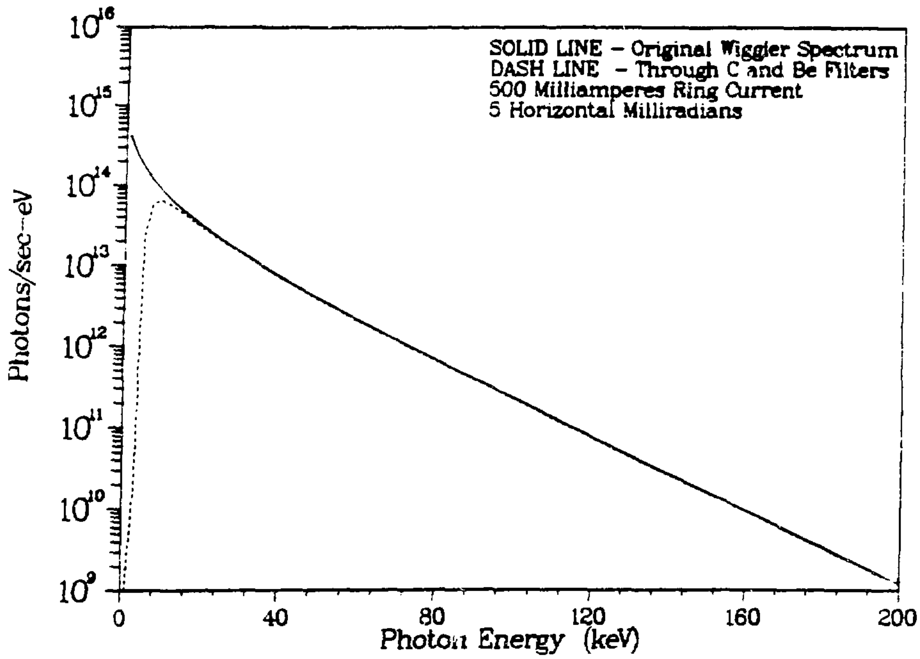

Figure 1. Superconducting Wiggler Spectrum. The Solid Line is the Spectrum Transmitted through Vertical Apertures. The Dashed Line is the Transmitted Spectrum through 15.4 mils of Graphite Filters and 20 mils of Beryllium Windows.

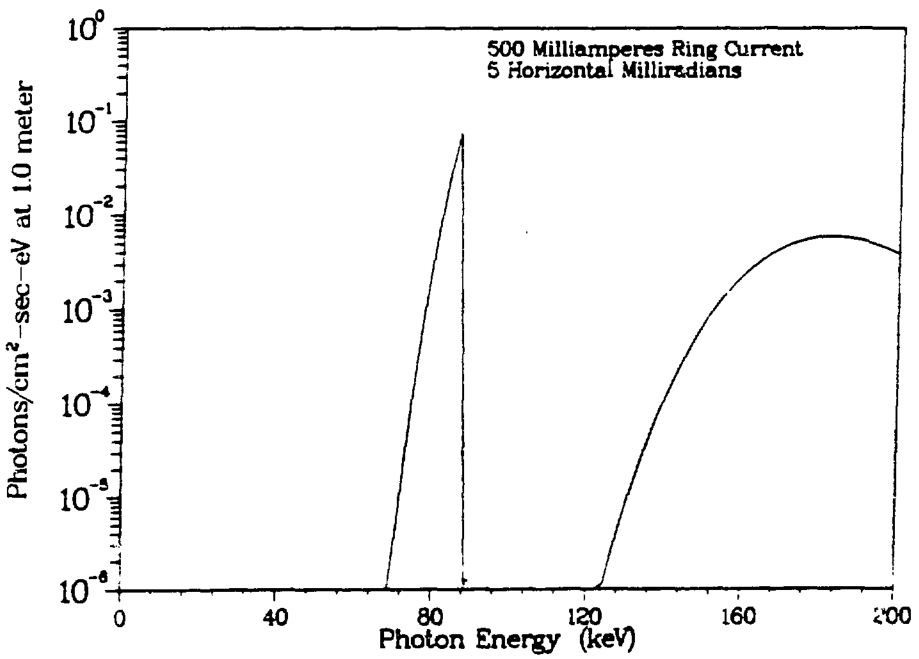

Figure 2. Transmitted Scattered Spectrum from Monochromator through Tunnel Shield Wall of 1/4 inch Steel and Lead.

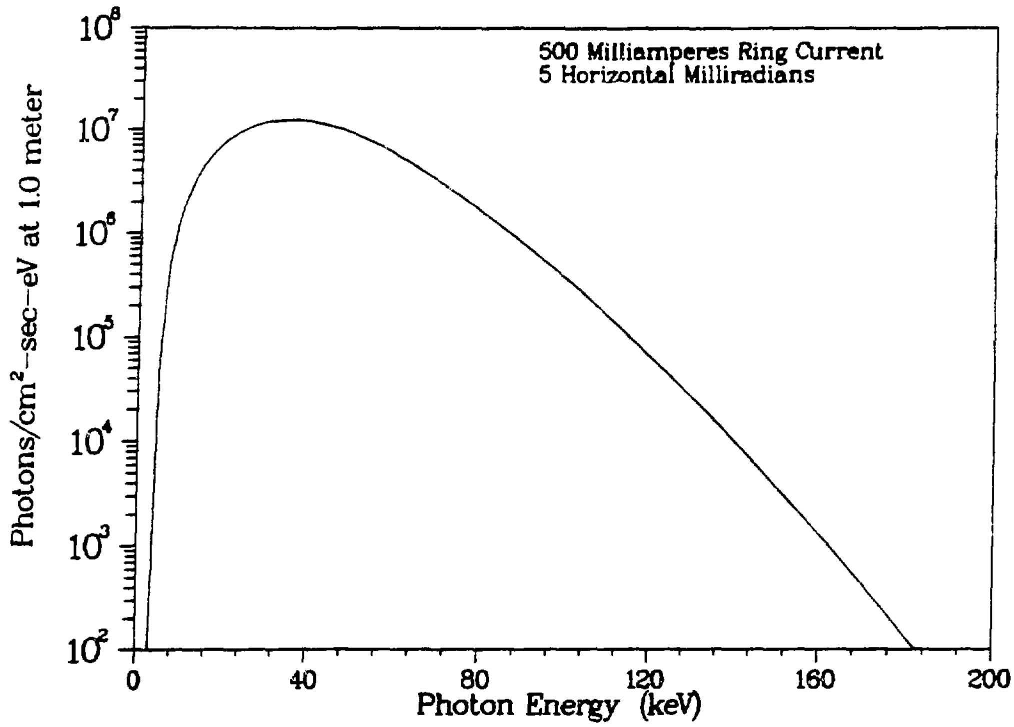

Figure 3. Transmitted Scattered Spectrum from Monochromator without a Tunnel Shield Wall.

Dose Conditions	**Dose Material**	**Total Dose (mrads/hr)**
Direct Filtered Beam	ICRU4	0.68E+15
Scatter thru Shield Wall	ICRU4	0.93E-01
(1/4 inch steel, 1/4 inch lead)		
Scatter without Shield Wall	ICRU4	0.15E+09
(zero thickness walls)		

Table 1: Calculated Dose to Standard Human Tissue (ICRU4).

From Table 1, it can be seen that the dose absorbed by a person in the direct beam is enormous as expected (a more realistic application would be to place before this a filter equivalent to the shutter block assembly).

The wall which follows the silicon crystal monochromator scatterer is the same that will be used in the X17 beamline tunnel construction. The tunnel will enclose most of the beamline downstream of the ring shield wall. This calculation shows that the doses expected are not large, about 0.1 millirads/hour under worst case conditions. In contrast, the dose without the tunnel shielding is unacceptably large (nearly a megarad per hour!).

Conclusion

PHOTON has proven very useful in the development of the X17 superconducting wiggler beamline. Its use has determined the shielding required from the wiggler device to the very end of the beamline in the hutches and angiography section. Doses calculated by this program have been compared with experimental results from conventional bending magnet beamlines with great success. In each case the program consistently overestimated the dose by factors ranging from 2 to 10. The reason for this overestimation is understood and was not refined further in the program in order to maintain some level of safety in the shielding calculations.

PHOTON should prove useful in the design of any beamline. Its ability to calculate power deposited and spectra transmitted through nearly arbitrary beamline configurations as well as the scattered radiation doses through shielding walls make it a very powerful tool.

A User's Manual to PHOTON is currently under preparation and will be available from the author.

We would like to thank Elke Braüer, without whose help we would not have completed this project and trusted its results. This work was supported by DOE contract DE-AC02-76CH00016.

References

[1] P. Suortti and W. Thomlinson, BNL Informal Report 34934 (1984).

[2] E. Braüer and W. Thomlinson, these proceedings, also, E. Braüer and W. Thomlinson, BNL Informal Report 39541 (1987).

[3] MAPPER version 4.0, Graphics code developed at Los Alamos National Laboratory by David A. Dahl. To be used with Display Integrated Software System and Plotting Language (DISSPLA). DISSPLA is a proprietary software product of Integrated Software Systems Corporation, San Diego, CA (1977).

[4] D.W.O. Rogers, Health Physics 46 (4),(1984) 891.