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A UNIQUE SAFETY MANUAL FOR EXPERIMENTAL PERSONNEL*

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The first radiation injuries were reported within six months of the discovery of X-rays (Ta71). More than thirty years have passed since the beginning of the atomic energy industry. During this period the quantity and application of radioactivity has increased enormously. Also, the complexity, beam intensity and numbers of radiation producing machines have increased remarkably.

In terms of total severity rates, accident prevention has been most effective where radioactivity and radiation producing machines are concerned. However, there is cause to believe that we may have reached or approached an irreducible minimum perhaps because the individual has not been sufficiently involved with personal safety. Various authors have estimated that greater than fifty percent of the serious radiation accidents are directly related to human failures, i.e., bypassing interlocks or violations of administrative procedures (Li68; Sc77). It is for this reason that we decided to share with the staff and visiting experimenters at the Stanford Synchrotron Radiation Laboratory (SSRL) the results of accidental but very high radiation doses delivered to human tissue.

While traditional training is an important and now a mandatory element of safety programs, it is important to recognize special needs when they occur. We refer to a new and expanding facility where highly educated and skilled investigators are conducting basic research. It is simply not sufficient to discuss regulations and numerical limits of exposure. It is also not sufficient, in all cases, to threaten violators with administrative sanctions to enlist their active support. We believe that it is equally important to inform each experimenter of the past and very real results of unnecessary risk taking. We propose to chronical the anatomy of each serious radiation accident in order to bring into sharp focus the results of some, perhaps a very small percentage of the total (Li68), of the more serious safeguard violations.

In spite of some opinions to the contrary, experimenters are human and therefore possess similar human responses to pressure that we all feel. Experimental apparatus and the experiments continue to become more complex and costly. Safeguards are often viewed as serious impediments to experimental necessity. When pressures mount and barriers are in the way there is strong desire to bypass such barriers.

The Stanford Synchrotron Radiation Laboratory (SSRL) utilizes the intense ultraviolet and X-radiation produced by a stored high-energy electron beam located at the Stanford Linear Accelerator Center (SLAC). The laboratory consists of two buildings housing the experimental equipment and support facilities. Experiments are designed around primary beamlines emanating tangentially from the SPEAR vacuum system. The synchrotron radiation beam is split into secondary beamlines by means of grazing incidence mirrors and crystals. The secondary beamlines then enter experimental enclosures. Presently, there are four primary beamlines servicing eleven secondary beamlines. The facility is designed to provide independent access to each experimental area. A broad range of research including UV and X-ray photo-electron spectroscopy, Extended X-ray Absorption Edge Fine Structure, X-ray diffraction on biological systems, Compton scattering, X-ray absorption, X-ray induced luminescence, sub nanosecond time constant measurements on solids and UV reflectivity is pursued (Wi74).

The most important property of synchrotron radiation from a radiation standpoint is the photon spectral distribution and intensity. The spectral distribution is a function of the stored beam energy and bending radius. The spectral distribution for several stored beam energies in SPEAR are shown in Fig. 1. The term critical energy is used in describing synchrotron radiation, half of the total power is radiated above the critical energy and half below. Figure 1 clearly shows the shift to higher photon energies as the stored beam energy increases. The intensity, for example, of 10 keV photons increases by a factor of 100 by increasing the stored beam energy from 2 to 3 GeV.

Measurements in the monochromatic beam using a 2.6 GeV stored beam with a charge of 22.7 mAmps revealed a measured dose rate of 5 rad/sec at 8.92 keV ± 1 eV. If this resolution were degraded to ± 1 keV then the dose rate could increase to 10,000 rad/sec. The continuous spectrum could increase the dose rate even more. Therefore, no open beamlines are allowed at SSRL.

An experimenter controlled personnel protection system was designed so that each experimenter is permitted access to the experimental enclosure by means of individual key control and interlocked panel without requiring further permission from outside

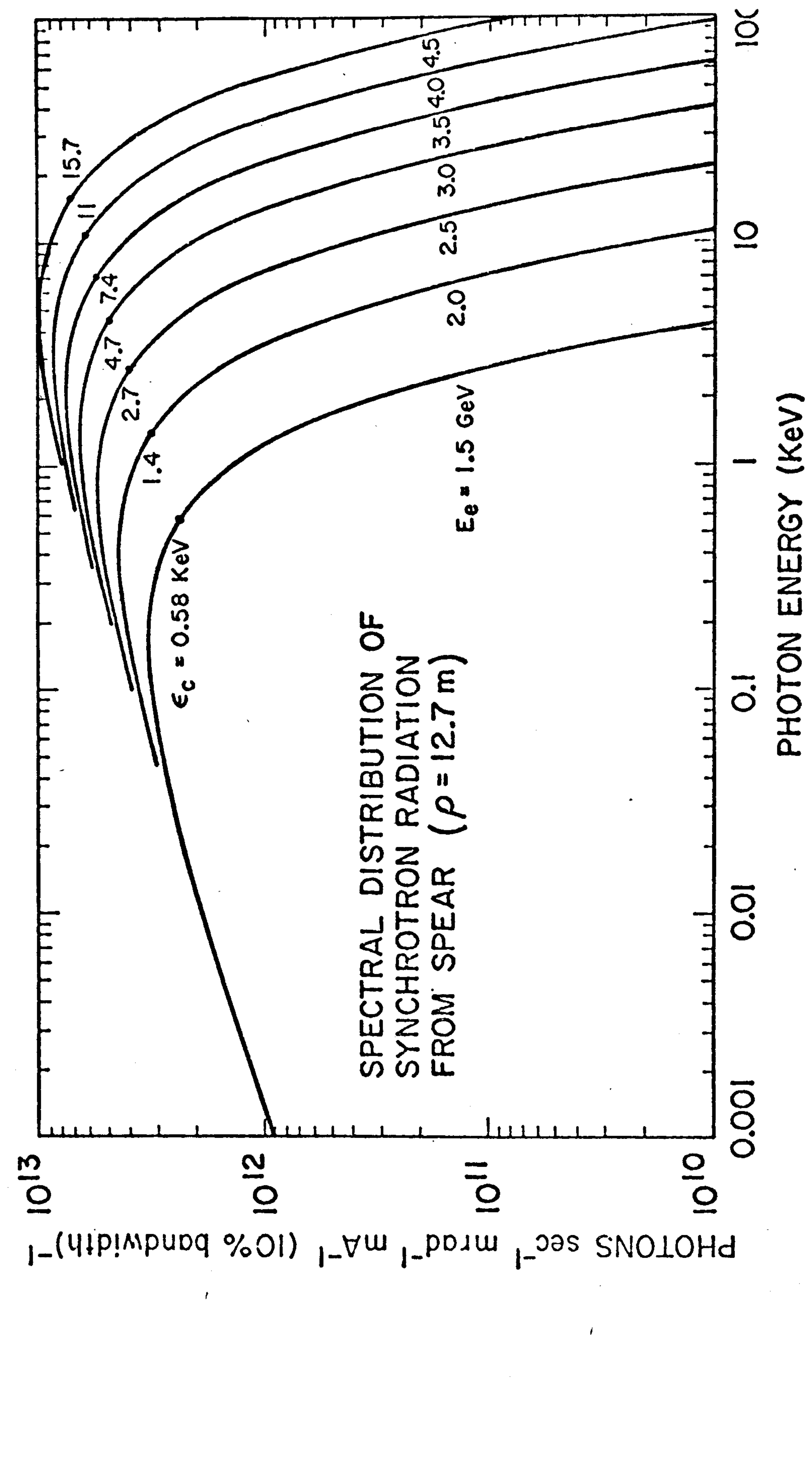
SPECTRAL DISTRIBUTION OF
SYNCHROTRON RADIATION
FROM SPEAR (ρ = 12.7 m)
ε$_c$ = 0.58 KeV
1.4
2.7
4.7
7.4
11
15.7
E$_e$ = 1.5 GeV
2.0
2.5
3.0
3.5
4.0
4.5
PHOTON ENERGY (KeV)
0.001
0.01
0.1
1
10
100
PHOTONS sec^{-1} mrad^{-1} mA^{-1} (10% bandwidth)$^{-1}$
10^{10}
10^{11}
10^{12}
10^{13}

Fig. 1

operators and independently of the conditions of other synchrotron radiation secondary beamlines. The experimental area control and personnel protection panel was designed on the basis of this requirement. This unit affords the experimenter the following control:

(1) Open and close beam stoppers.

(2) Key release for entry into enclosure.

In addition there is an on/off line key which allows SSRL staff personnel to lock stoppers in place while experimental enclosures are being modified. The experimenter is therefore not able to bring experiments on-line until the staff operator removes the primary beam stoppers. SSRL operates around the clock when SPEAR is running. Experimenter personnel come from many institutions from all over the world. The SSRL staff has the responsibility to provide a safe working environment and to make sure the equipment is used in the prescribed manner. It is therefore essential to enlist the willing support of experimental personnel by a variety of approaches.

SSRL administrative and engineered safeguards are explained. There is also a detailed administrative procedure to deal with violations when and if they occur. Finally we are preparing a well-documented manual of machine accidents along with graphic depictions of the resultant injuries. Each experimenter is required to review SSRL safety policies and procedures prior to putting their experiment on-line. They are also required to review the Accident Manual. Each accident cited is referenced and accident reports or copies of journal articles are on file in the event an experimenter wishes to explore, in greater detail, the nature of the cited accidents.

We present here one example of the contents of the manual along with the narrative format (see Appendix). At the present time it is incomplete. As approval for reproductions of accident results are received they will be added to the manual.

ACKNOWLEDGEMENTS

We are grateful for the cooperation of Dr. L. E. Lanzl of the Department of Radiology and the Argonne Cancer Research Hospital for making the clinical photographs available.

REFERENCES

Li68 Lindell B., 1968, "Occupational Hazards in X-ray Analytical Work," Health Phys. 15, 481.

Sc77 Schüttmann W. and König W., 1977, "Conclusions from Some Unusual Events in the Field of Ionizing Radiation in the German Democratic Republic," page 21 in Handling of Radiation Accidents, IAEA Publication STI/PUB/463 (International Atomic Energy Agency, Vienna).

Ta71 Taylor L. S., 1971 Radiation Protection Standards (CRC Press).

Wi74 Winick H., 1974, "The Stanford Synchrotron Radiation Project (SSRP)," SLAC-PUB-1439.

APPENDIX

REVIEW OF MACHINE PRODUCED RADIATION ACCIDENTS

Prepared by

Operational Health Physics Staff
Plant Engineering Department

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September 1979

Under contract with the

Department of Energy

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PREFACE

Within a few months of the discovery of X-rays the first radiation injuries were reported (Ta71). During the past thirty years both the number and complexity of X-ray analytical units have increased markedly. The world-wide number of incidents leading to severe injury has also increased.

For analytical X-ray machines the need for engineered and administrative safeguards has long been recognized. At SSRL the personnel protection system has been carefully designed to maximize safety and minimize experimental interference. However, all possible experimental configurations cannot be anticipated and some interference is to be expected.

There are means by which safeguards can be substituted as long as these substitutions do not degrade the existing degree of safety. Any substitutions must be evaluated by the Radiation Safety Committee, the SSRL staff and Operational Health Physics.

Some studies have indicated that between fifty and ninety percent of serious radiation accidents are directly related to human errors, i.e., ignoring administrative procedures, by-passing engineered safeguards or by inadequate training (Li68; Sc77).

Lindell (Li68) has estimated the annual probability of serious injury to be about 1:100 per machine. No matter what the real probability of serious injury is the personnel protection system should reduce this risk to a value that approaches zero.

It is hoped that this manual will bring into sharper focus some of the more serious results of unnecessary risk taking. We also hope that it will convey the very real necessity for safeguards which may at times appear to be arbitrary and unnecessary impediments to experimental purposes.

CASE HISTORY

Description - An industrial worker was accidently exposed to 10 MeV electrons when he entered a room in which a linear accelerator was operating.

Dose Determination Based on Phantom Measurements

for 8.5 Second Exposure

Location		Dose, rads
Right hand,	thumb,	240,000
	little finger	42,000
Right foot,	ankle	29,000
	toes	11,000
	foot (arch)	300

Results - Very high dose to the right hand and lower right leg resulted in double amputation approximately six month's following the exposure.

Contributory Factor - A key operated interlock was effectively by-passed by the installation of a double door allowing the worker to open the lower half stooping under the door and entering the accelerator room.

Literature Citation

Lanzl L. E. et al., 1967, "Injury Due to Accidental High-Dose Exposure to 10 MeV Electrons," Health Phys. 13, 241.

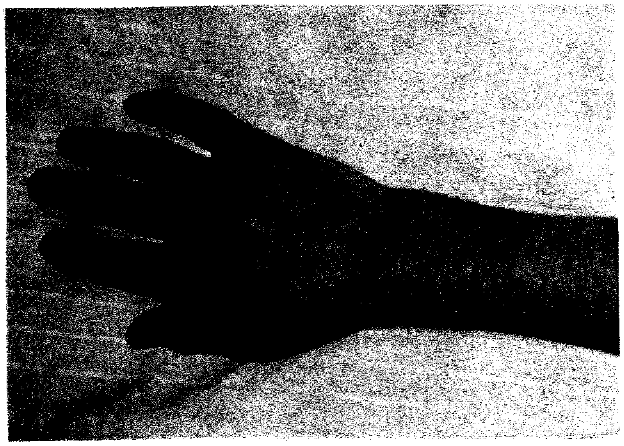

Fig. 2. Right hand post accident day 2.

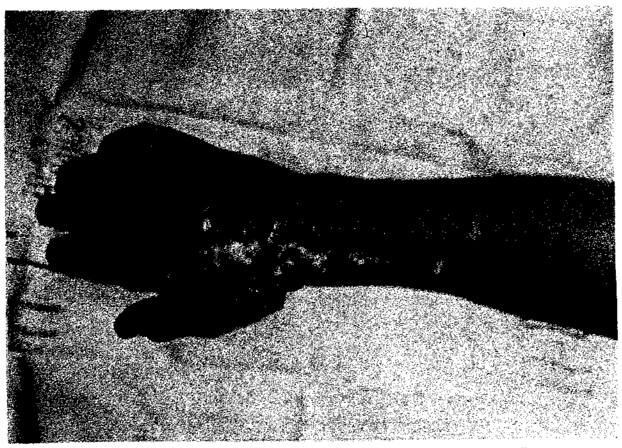

Fig. 3. Right hand post accident day 4.

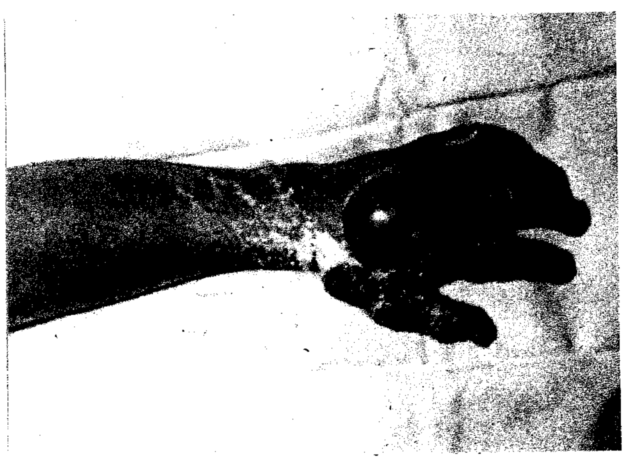

Fig. 4. Right hand post accident day 7.

Fig. 5. Right hand post accident day 11.

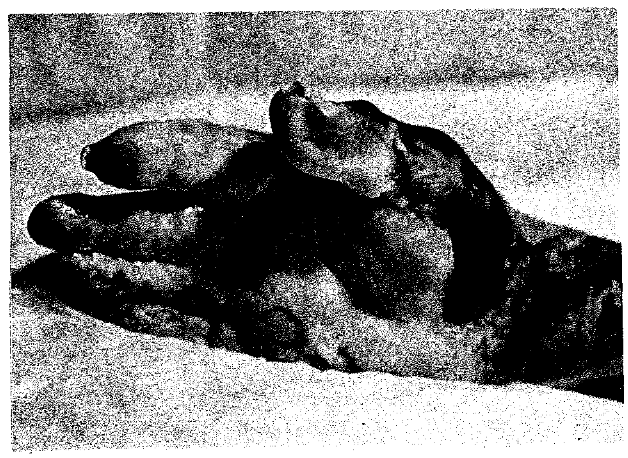

Fig. 6. Right hand post accident day 36.

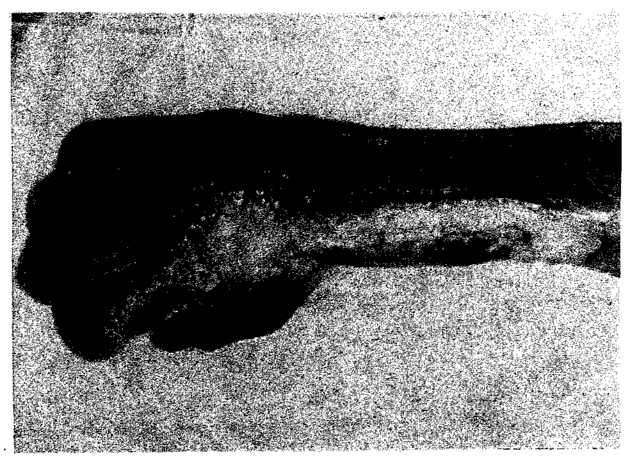

Fig. 7. Right hand post accident day 100.