

**Radiation Safety around High-Energy Particle
Accelerators
(as seen with the benefit of hindsight)**

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Too Soon Old -----Too Late Smart!

Gordon Livingston, M.D., 2004

ABSTRACT

Looking back on a career of being responsible for radiation safety, involving many types of accelerators, this paper describes incidents that happen in radiation protection that cannot be reasonably anticipated but might with avoided by imaginative thinking and some understanding of human behaviour. This lecture discusses improvements necessary in procedures, hardware, and beam dynamics which, if rigorously implemented throughout the accelerator world, in all accelerator areas, independent of the place or accelerator type being used, would ensure safety measures of a uniformly high standard.

FOREWORD

This paper is not intended to summarise the history of radiation safety around accelerators but to comment on some of the aspects that could be improved involving health physicists, accelerator development engineers, and electronic instrument engineers. Attention is drawn to problems that occurred and with which I have had to cope in my professional life, with some suggestions for improvements.

My apologies if these problems sometimes seem trivial and may have been already solved. (Bear in mind that I have been retired for 14 years now!) In making these comments no adverse criticism of colleagues (or, indeed, anyone else) is intended. Rather it is hoped that all colleagues who participated in the setting up of successful radiation safety systems decades ago (when the world was young) may share the honour of this award!

I would like to make it clear that my affiliations are known but the positions presented here are entirely my own and hence I am entirely responsible for them. If further discussion or comment is needed, please contact me by e-mail at anthony.sullivan@onetel.net. I should be most happy to hear from old friends!

I regret that, owing to poor health, I am unable to travel to Portland to deliver this lecture in person and am indebted to the Accelerator Section of the Health Physics Society for arranging to have this presentation made on my behalf.

I wish you all a pleasant conference there in Portland.

INTRODUCTION

In preparing this talk I have come to realise that to look back on experiences several years after being involved with accelerator radiation safety can be enlightening and I wonder what progress has been made in the years since my retirement. Restrictions are nowadays no doubt more severe than when I was working at CERN. National regulations and limits continue to become more restrictive, partly because of both better awareness of the consequences of radiation exposure and its effects but also because of increasing public sensitivity to radiation exposure.

Several points come to mind:

- Information based on traditions or experience now lost in the mists of time, or just based on simple rules of thumb, need careful review after the fact, whenever the opportunity arises. For example, when dismantling an installation, it can come as a shock to discover that safety measures installed in earlier days did not in fact afford

the intended protection (but taken to be true based on hearsay).

- Where were the real problems in the past as now seen with the benefit of hindsight?
- Why do experts and senior personnel behave as they do?
- What is the real purpose of their actions?
- Is there too high a price put on safety?
- Why were some aspects of accelerator operation not optimised or modified with radiation safety in mind when the machines were first laid out?

And lastly:

- Who is finally responsible for the result?

The senior person responsible for radiation safety at an accelerator cannot be the final arbiter because of a double loyalty. He or she is effectively responsible to both the management and to the personnel and hence has to balance risk against cost. Following the manner of the best naval tradition exemplified by “the captain going down with the ship,” it is the most senior person in the organization, be it Director, Chancellor, or CEO, who is ultimately responsible. Persons with influence in the hierarchy (and even lesser mortals) need to be satisfied by consistency in the advice they receive and hence – seeing that similar problems require similar solutions – will thereafter show confidence in your recommendations. Inconsistencies can be glaringly obvious. Keep good records so that you know what you suggested on previous occasions and only change things if the previous efforts were not too successful. Finally, problems cannot be ignored and have to be solved one way or another even with limited knowledge, and reasonable best advice must be given as quickly as possible.

RADIATION ACCIDENTS

Experience shows that injury (or worse) due to radiation is more likely to result from human errors and reactions rather than by particle beams. No doubt there are many apocryphal tales of incidents “best forgotten.” For example, the following events happened at a laboratory that shall remain unidentified. Imagine the following scenario:

The health physicist is on holiday. In a “hot” target area, someone notices a trickle of water on the floor; the Prima Donna of a team leader decides it must be radioactive and

hence dangerous. This particular group leader is far too senior to be influenced by the advice of a humble health physics technician. Where is the sump to collect the water? One is not immediately obvious. Panic, let us dig one; easy, says his deputy, we will go and get in the diggers; and in a few minutes, they have smashed through the main drain that already had a very adequate collection delay tank. This drain releases its contents and the trickle becomes a flood! Call the fire brigade, who are well known to be capable of dealing with any emergency but are a bit sensitive about things radioactive. The fire brigade members examine the problem and all agree that the drainpipe needs to be capped. One of the fire fighters knows a downtown hardware store that would have the very thing. The chief of the fire service is known to be in town, so the fire brigade calls him on the emergency radio! The Fire Chief gets the urgent message and reacts by getting into the fire-car he is using, turns on its flashing light and siren, momentarily oblivious to the fact that his wife (against all regulations to the contrary) is sitting in the official car. While roaring across town, he hits another car and his wife ends up in hospital.

This action has involved several illegal or illegitimate manoeuvres and required a mammoth public relations exercise to keep the story out of the press. Meanwhile the poor woman was an indirect victim of radiation, through an overreaction by unqualified but “important people,” without ever being near any source of radiation!

SAFETY INTERLOCKS

The most serious accident would probably occur due to interlock failure, either mechanical problem or failure in a computer-controlled chain. Standardisation of interlock logic is required. Both the logic of interlock chains and hardware should be reasonably transparent so that experimenters may be sure they are reasonably protected wherever and whenever they might be working and

- A red light for “beam on or ready for on” and green light for “beam switched off; safety-interlocks in operation.” These should have the same meaning worldwide.
- As well as interlock procedures, the search and clear of machine and beam areas should also be standardised.
- Instruments for measuring pulsed radiation outside accelerator need improvement.

With the abundance of available microprocessor chips, it should be possible instead of

just taking an average reading, to program a hand-held ion chamber instrument to integrate the signal during a beam pulse and then calculate the resulting dose rate and display it in the required units, then repeat the cycle by resetting to zero until the expected arrival of the next pulse to re-evaluate the dose. Such a system would greatly increase sensitivity by increasing the signal to noise ratio.

In order to avoid unnecessary discussion, particularly with hypersensitive individuals, as to the dose or dose-rate that can be tolerated for radiation workers, visitors, or contractor personnel, it is desirable (essential) to be able to consult a document that has been agreed upon by all the “stakeholders” (management, trade unions, and staff associations) and written to provide an agreed-upon protocol that can quickly settle any argument. This document could also specify emission levels in air and water that do not require detailed monitoring or analysis. It could also detail what to do in case of a suspected accident.

Another area that requires standardisation is the uniformity of warning signs and area designations that must be easily recognisable and be related to possible dose rates in a similar and consistent way.

USE OF COMPUTERS

Computer programmes can help considerably when used properly and not just to indicate that everything is known. A good (but sometimes false) impression can often be made by producing a computer printout at a meeting and hence implying that you are capable of answering any question. As programmes become more sophisticated, detailed problems may be solved if sufficiently detailed beam and shield information can be entered.

Who is responsible for the output data when the result is attributed to a programme with a given name? Independent checks are essential to authenticate the result. The idea that given sufficient beam details, any radiation problem can be solved by using a sufficiently detailed programme is hard to accept.

Computer and beam control software should be beyond question.

WHAT MAKES BEAM OR TARGET AREAS SAFE?

As well as switching off the machine, back-up measures are necessary before access to potentially lethal primary beam areas can be allowed. The commonest element in a safety chain is often a beam stopper of thickness greater than the range of the primary beam

particle; knowing such a thing is stopping the beam is only superficially reassuring.

When hit, the beam stopper will effectively act as a thick target and the area has to be shielded accordingly. Secondary particles will pass up the beam channel and reliance cannot be put on upstream beam elements absorbing the unwanted radiation but an efficient collimator should be provided. Radiation monitors are not considered sufficiently reliable to be in an interlock chain. What is needed is a beam fuse where the beam self-destructs in undesirable modes of operation.

Internal circulating beam stoppers can also make problems.

Why is it that muons, produced by pion decays, which easily penetrate the shield often appear above the horizontal plane? It should be possible to reconfigure the mechanism so that the primary beam is directed downwards onto the target thereby burying the unwanted radiation (turn the thing upside down?).

RADIATION MEASUREMENTS

The problems of radiation measurements have been reviewed many times and I suspect that results would be similar whatever group does the measurement. All systems are based on determining different parts of the radiation spectrum. Methods for the high-energy component usually depend on activation analysis, whereas the rest of the spectrum can reasonably be determined with hand-held instruments. The reaction thresholds and cross-sections of commonly used activation detectors, such as carbon and aluminium, need to be internationally agreed and standardized. Whatever happened to the much-vaunted bismuth fission chamber?

THE REAL PROBLEMS

Despite being able to reasonably predict radiation levels outside shields, unknown factors remain that can undermine your efforts as exemplified in the following two actual cases.

As part of a very expensive shielding improvement project, a shield with a personnel access chicane was required. This was designed with extreme difficulty. The plans were accepted by the leader and signed. When tested the shield was far less efficient than expected. Further investigation showed that technicians with influence had modified the construction to ensure they could get their equipment through, as the next nearest alternate access was a considerable distance away.

In another case, a higher than expected radiation level was detected outside a chicane for emergency escape from a target area. Inspection of the official drawings showed that a modification had been made to the original design, effectively short-circuiting the last bend of the chicane and affording its open entrance a good place to shelter from the weather. The technician responsible was forcefully reminded that he was not allowed to alter anything in the official plan without permission. It all had to be put right in a hurry. I feel sure most accelerators have similar tales of expert technicians modifying things for their own convenience, hoping that the changes will not be noticed. Perhaps such possibilities have to be foreseen and taken into account in the initial design?

A common sin is to be seduced into making concessions to expedite ongoing work before operations have started. For example: *“Could please the last layer of concrete be left off the secondary beam switching area, as it has to be removed every time a magnet needs repositioning?”* In a weak moment an agreement to this “reasonable” concession is made but, without constant vigilance, the shield may well remain permanently weakened. You will have to live with the consequences of such decisions, no matter whether trivial or serious.

I wonder how many similar incidents have taken place without being noticed. An accelerator laboratory needs a works inspector or “clerk of the works” who is responsible to ensure that plans are strictly conformed to. Modern well-designed shields offer safety margins that leave little leeway for modification. As a legal matter it may be necessary to require that the leader of the team actually installing the shielding certifies in writing that the installation fully corresponds with the drawing supplied.

Ageing and crusty ventilation engineers are a law unto themselves and are so used to installing very extensive systems in industrial environments that they often need retraining to understand the intricacies when radioactive gasses are involved. Mention a carbon filter and they practically go apoplectic!

CONCLUSIONS

Radiation safety around accelerators appears to be in good shape, although the real problems sometimes may take you unawares. The answer would be to educate the personnel right up to middle management. Things could be improved by taking on board an accelerator physicist or engineer as part of the protection team.

In addressing the elite of radiation safety around accelerators the opportunity must not be

allowed to pass without suggesting – nay urging – that they get together to take the initiative in persuading the accelerator engineers to change their attitude from designing “one-off radiological protection systems” to agreeing on what should be the norm throughout the world. A universal radiation protection manual needs to be produced for informing the entire accelerator work force on what the problems are and where the responsibilities lay. This manual must be strictly enforced before an accident shows such a necessity.

ACKNOWLEDGMENTS

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REFERENCES

To avoid complicating the presentation I have not made individual references, as explanations of all terms and quantities are comprehensively found in the following books:

Wade Patterson, H. W., and R. H. Thomas. *Accelerator Health Physics*, Academic Press, New York (1973).

Sullivan, A. H. *Guide to Radiation and Radioactivity Levels Near High Energy Particle Accelerators*, Nuclear Technology Publishing, Ashford, Kent (1992).