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Levels of Radiation

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THE FIRST professional radiation scare occurred in 1905. It was followed by a public radiation hysteria. This was excusable. The professional scientists and physicians who were then working with radiation were working with something that was largely unknown. The second wave of radiation hysteria occurred in about 1925. This, to a certain extent, was excusable also. We were just then beginning to define the ideas of quantity and quality of radiation. The professional radiation scare that is just now subsiding is not excusable. We have had 50 years of radiation experience and everything we know about radiation protection was already well known to many professional people and had been thoroughly discussed in the professional literature before World War II. The current wave of public radiation hysteria is less than excusable, for it appears to have been manufactured. The reason that it could have been manufactured is apparently due to the shift away from the idea of "personal safety" to the idea of "maximum permissible safety for personnel." This is a case of letting someone else take care of radiation safety. Radiation safety cannot be delegated.

Before one can speak of the effects of radiation on man (biological, sociological, or political), it is necessary to establish some perspective on the levels of radiation to which man can be exposed. Apparently we are having a great deal of trouble in teaching the public that there is a difference between big and little. This is not hard to understand. We are also having a great deal of trouble in teaching physicians that there is a difference between big and little, and physicians have a long history of working with the concept. A large amount of almost anything, when introduced into the human body, is dangerous, but a small amount of almost anything, when introduced into the body, is not dangerous. A large amount of aspirin given to a small baby can be fatal; a small amount of aspirin given to a large man can be innocuous.

With some materials the situation is not quite so simple. If a man should breathe a large amount of anesthetic ether, he could be killed. If he breathes just exactly the right amount of anesthetic ether, it might do him some good and is very necessary to life under certain circumstances. It does not do a man any harm, but neither does it do him any good, to breathe very small amounts of anesthetic ether. If we want to take a 100 per cent safe position, we should say that a man should breathe no anesthetic ether at all. Still, this would not necessarily be the 100 per cent safe position, because under very special circumstances (after severe injuries, for example) just the right amount of anesthesia helps the body to get over the initial biological insult of trauma.

A very similar situation exists with radiation. If, for the time being, we do not try to make very accurate measurements of what we mean by large and small, we can say the same thing about radiation that we say about anesthetic agents. A large amount of radiation is harmful, but just the right amount of radiation is sometimes necessary for human life. The question of whether a small amount of radiation is necessary or desirable is academic, although interesting. The fact is that there is always a small amount of radiation present, and a biological organism cannot get away from radiation any more than the earth can get away from rotating.

There is another way of looking at the radiation problem. For example, if I were to throw any man into the middle of the Pacific Ocean, he would drown. No man can swim the Pacific Ocean; therefore, I might say that water is dangerous because it kills people. On the other hand, if I were to withhold a glass of water from a man for a long time, he would also die; therefore, I might say that water is necessary to life.

The same thing may be said of radiation. If I were to expose a man to the radiation from an atomic bomb, I could kill him. Therefore, we can say that radiation is dangerous. But if I withhold a necessary x-ray examination from a sick man, I could also kill him. Therefore, we can say that radiation is necessary for life. Both these statements

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are true, yet both are false because each considers only a small part of the problem.

Measurement of Levels

Megacurie Levels.—To teach physicians that there is a "big" and a "little" in radiation as well as in every other kind of subject matter, Table 1 contains data on the levels of radiation. In preparing this table I could have used any of the units that measure radiation, but I preferred to use the curie. It's true that this unit measures the source of radiation, not the radiation itself, but because people buy curies (or millicuries) of radioisotopes, they are already educated to some understanding of much and little. (Everyone understands much and little money.) We can define a megacurie amount of radiation—it is a million times greater than the curie. This is a disaster level from the viewpoint of most physicians, but it is not *necessarily* a disaster level. Just as people can work in and around the Pacific Ocean without being drowned, people can work in and around megacurie levels of radioisotopes without being hurt.

TABLE 1.—Levels of Medical Concern

Level	Curiage	Symbol	Name of Level
10^6	Megacurie	Mc	Disaster
10^3	Kilocurie	Kc	External therapy
10^0	Curie, 37 billion disintegrations per second	C	Radiation effects
10^{-3}	Millicurie	Millic	Internal therapy
10^{-6}	Microcurie	Microc	Diagnostic
10^{-9}	Millimicrocurie	mμc	Tracer
10^{-12}	Micromicrocurie	μμc	Low level

Kilocurie Levels.—We can talk about kilocurie amounts of radioisotopes. This is a thousand times greater than a curie. It is now routine for physicians to work with thousands of curies of radioisotopes, commonly called an external-therapy level of radiation. In 1959 physicians from the United States and Canada purchased 353,000 curies of cobalt-60 to use in teletherapy machines. We might say that this is not a dangerous amount of radiation because people work with teletherapy machines every day and no one has yet been hurt. On the other hand, however, this is a dangerous amount of radiation. If it were improperly used, people could be hurt and hurt seriously with kilocurie amounts of radioisotopes. The methods of handling this amount of radiation are just as stringent as the rules of safety that a fisherman uses in fishing the Pacific Ocean.

Millicurie Levels.—We can go in the other direction and take a level of radiation a thousand times less than the curie. The millicurie is a unit used in internal therapy. The use of radioactive iodine is the commonest example; millicuries are used to treat hyperthyroidism. The essential method of therapy here is to destroy a portion of the thyroid gland. Nevertheless, if this is a sufficient amount of radiation to destroy one tissue, then it certainly can be misused to destroy many tissues.

Microcurie Levels.—We can go down another thousand steps and take a millionth of a curie. This is called the microcurie level of radiation. It is a diagnostic level that physicians commonly use to make diagnoses of various diseases. The physician uses this level without trepidation, but he uses it with a purpose.

Millimicrocurie Levels.—When the medical scientist wants to be exceptionally sure that the level of radiation he is using in studying disease does not make any difference in the body economy, he goes down another thousand steps and uses the millimicrocurie level, a billionth of a curie, commonly called the tracer level. By definition a tracer is something that does not affect the body; it does not change the system that is being studied.

Micromicrocurie Levels.—Under special circumstances and with very special equipment the medical scientist may want to go down another factor of a thousand to the micromicrocurie level. This is exceedingly low-level radiation. It is actually a thousand-billionth of a curie. This is below the level of background radiation—the level that is always present. No one as yet has been able to measure a micromicrocurie of radiation in the human body because a hundred times more than this is already present in the body.

The Preferred Instruments

The range of levels of radiation that we are talking about extends all the way from atomic bombs to the measurement of carbon-14 in ancient materials. The instruments (Table 2) that we use determine to a large extent what we must do with radiation, the kind of materials that we work with, and what we must do to protect ourselves. For example, at the megacurie or disaster level, we use special instruments for measurement, and the radiation protection problem (the monitoring that we do to protect ourselves) is very special. Many radioactive isotopes are present at disaster levels of radiation, and the problems are exceedingly complex.

TABLE 2.—The Preferred Instruments

Measurement	Radiation Monitoring	Common Isotopes
Special instruments	Special instruments	Sr^{90}-Cs^{137} About 200 others
Ion chamber	Pocket dosimeter	Co^{60}-Cs^{137} Ir^{192}
Ion chamber	Pocket chamber, pocket dosimeter, film badge (weekly)	Co^{60}-Cs^{137} Ba^{140}-La^{140} Ta^{182}
Electroscope	"Cutie pie," pocket chamber, film badge (monthly)	I^{131}-Au^{198}-P^{32} Lu^{177}-Y^{90}
G-M tube	Laboratory survey meter	I^{131}-Cr^{51}-Co^{60} Rb^{86}-As^{74}-Cu^{64} Na^{24}
Scintillation crystal	None	C^{14}-S^{35}-Na^{24} C^{140}-F^{18}
Shielded anticoincidence counter	None	K^{42}-Rb^{226} C^{14}-Na^{22}

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At the kilocurie level of radiation we ordinarily use an ion chamber for measurement. But this is a dangerous level of radiation by one method of defining danger and so we use a special kind of ion chamber, a pocket dosimeter, to monitor our procedures. We must have instantaneous readings, because here "instants" are important lengths of time.

When we go down to the internal therapy level, the millicurie yields an insufficient amount of radiation for the ordinary ion chambers to be used. Here we use an electroscope. The electroscope is not the only instrument used, but it is preferred because it does measure remarkably well at the levels we are talking about. The monitoring we do at these levels does not have to be so "instantaneous" or quite so precise; we can therefore use other kinds of monitoring devices. Even the film badge, ordinarily only a legal and administrative protection, is useful in personnel monitoring.

When we get down to diagnostic levels of radioactive isotope use, the instrumentation problem changes. We once used (and investigators in some countries still use) the old Geiger-Müller tube, or, rather, new developments in the old Geiger-Müller tube idea. Now we are shifting to scintillation crystals.

At this point the monitoring problem changes and we no longer worry about the effects of one diagnostic dose on one person. At the diagnostic level, instruments of measurement are far more sensitive than the human body and therefore we have a different problem, the problem of protecting instruments, not people. If an instrument can be used to measure diagnostic levels, it can be contaminated with these diagnostic levels, and therefore the "health physics" problem becomes much more a problem of protecting instruments than it is of protecting people.

There is another reason for changing our ideas of personnel monitoring at the diagnostic level. Very seldom is one diagnostic use made of a radioisotope; usually many diagnostic tests are done on many people. Therefore, a minor mistake can be repeated many times with a build-up of contamination that could reach far beyond the diagnostic level. The health physics problem is not one of worrying about "one person" at "one time." It is a problem of worrying about the continuous use with "many persons" over "many times," so that there may be a gradual build-up of contamination that is or is not noticeable.

The use of tracer levels of radioactive isotopes is a situation that is changing along with the change in diagnostic levels. Along with this change, diagnostic levels of radiation are gradually becoming lower. This is not because it is more dangerous to use diagnostic levels and less dangerous to use tracer levels, but because the diagnostic procedure is more precise with tracer levels than with diagnostic levels.

The problem of protecting instruments is a serious one. The build-up of contamination with tracer levels is not less, but it is less noticeable and it affects the instruments less. Therefore, the health physics problem of protecting instruments from contamination at tracer levels is easier to cope with. The monitoring problem in the protection of people is nonexistent.

But this whole situation concerning instruments and "radiation protection" changes again when we get down into the micromicrocurie levels. Just after World War II it became possible to measure, in specially equipped laboratories, the amount of carbon-14 in ancient materials. It also became possible, with increased technical proficiency, to measure the amounts of radium that had been deposited in the body 20 and 30 years before. The idea of measurement of whole bodies was conceived. It also became possible to study the problem of background. The amount of potassium activity present in the human body is an important subject in medicine, but first of all one has to consider seriously the amount of potassium that is in the glass that makes up the photomultiplier tube that is an essential item in a whole-body counter. When we can measure the amount of radiation in the human body at these exceedingly low levels, then we can also measure the amount of radioisotope deposited in the body from the distant fall-out of atomic bombs. Just 15 years ago the presence of cesium-137 in the human body was not a problem, not because it didn't exist, but because there were no instruments capable of measuring it. A half-century ago the amount of radiation from the natural potassium in the body was not a scientific problem, not because there was no radioactive potassium in the body, but because there was no machinery capable of measuring it. Therefore, it was "not a problem" by default. It was suspected by very astute scientists and even demonstrated with autoradiography; but the suspicion was a half-century too early. Still, it was not really too early, because the development of exceedingly fine detecting instruments owes a great deal to the irritating suspicions of astute scientists.

In a sense we can say that there is no health physics problem and there is no "danger" in these very minute tracer and low-level measurements. In another sense, however, the health physics problem has changed and now we must be worried about instruments. We might even begin to think of the effects on human beings of these low levels of radiation. This does not make radiation dangerous in the ordinary sense that we use the word dangerous. It does mean that we can now "suspect" and "postulate," just as the old-time pharmacologists suspected and postulated about minute amounts of herbs, salt, water, and all the other naturally occurring materials. The bulk of medical science is

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not concerned with fancy wonder drugs; it is concerned with normal every-day events of living.

Safety

Probably the most important of all the subjects that go along with a knowledge of the levels of radiation is the question of safety. But this, to a large extent, depends upon our definition of safety. We are really interested not in the "maximum permissible dose," but in a "safe" dose.

After a half-century of investigation and after serious thought on the part of many serious scientists, we still do not know what the word "dose" really means. Or rather, we have so many definitions that in effect there is no definition. No one can give "permission" or can withhold "permission" for the very low levels of radiation, yet at high levels we can either produce or not produce radiation and so someone can give permission. The word "maximum" is the hardest of all. A quarter of a century ago medical scientists were interested in the "tolerance" level. How much could we tolerate without being unsafe? Discarding the words "safe" and "tolerance" may allow governments to skirt the problem, but it does not remove it.

What we are still interested in is how much radiation is "safe," and there is no all-inclusive answer to the general question. It is "safe" for a well-educated radiotherapist to use kilocuries of a radioactive isotope in a teletherapy machine; it is "unsafe" for an untrained child to use the machine. It is "safe" for a well-trained internist to use millicuries of radioactive iodine in treating a disease, but it is "unsafe" for an untrained physician to use radioactive iodine. It is "safe" for a well-trained and sophisticated physicist to use a complex photomultiplier tube in detecting low levels of radiation, but it might be "unsafe" for a physicist untrained in the field of radiation measurement to attempt to interpret the meaning of background.

The Basic Tools

The tools that we use in the routine safety problems are already well defined, although their design is not static. These tools are changing and, fortunately, changing for the better with each advance in instrumentation. The tools in the field of medicine (Table 3), which probably encompasses the largest range of effort within all the levels of radiation, to a large extent determine what we mean by "safety." The person who is working with a large amount of radiation should use an instrument that tells him instantly how much radiation he has received. He must be a sensible person and he must be a person who has at least a minimum of training. For the technician who can be trusted, the pocket dosimeter is the instrument of choice. There is, however, another problem: the administrative and legal problem of recording the radiation persons have received. For this purpose the pocket chamber is used. It is adequate for untrained technicians, but here the definition of safety must change. A sensible administrator must be able to guarantee, within reason, that untrained technicians are not being unduly exposed.

Because of the way our laws are written we usually need evidence of exposure. The film badge is a kind of legal protection, but it is not protection for the person. It takes time to process a film badge. If the danger is actual the monitor needs to be instantaneous; but if the danger is potential, "watchfulness" and not "protection" is needed.

A simple definition of the levels of radiation is really an oversimplification. Millicuries of some isotopes are exceedingly dangerous, whereas millicuries of other isotopes have little or no radiation danger. Various kinds of laboratory counters are necessary, not only for monitoring but also for the study of almost any kind of science in which radioisotopes are used. Fortunately for the health physics problems, the protection of these laboratory counters is usually more critical than the protection of personnel. This sensitivity of the laboratory counters is probably the best kind of health physics protection we have. It is what makes radioisotopes one of the safest of the poisons that can be used in studying the life sciences. The investigation of carbon monoxide, for example, is dangerous because the instrumentation for detecting and measuring carbon monoxide is so complex. The investigation of radioactivity is safe because the instruments for detecting and measuring radioactivity are so simple. The cheap, prevalent, and easily maintained laboratory survey meters have helped to make radiation a routine laboratory phenomenon. It is necessary to be eternally vigilant with laboratory survey meters, but this is the price and the real meaning of safety.

TABLE 3.—The Basic Tools

Tool	Applicability
Pocket dosimeter	For a sensible, trained technician who is trusted
Pocket chamber	For sensible administrators and untrained technicians
Film badge	Good legal protection; poor radiation protection
Laboratory counters .	These need more radiation protection than personnel do
Laboratory survey meter	The best kind of safety device every laboratory needs one

Overemphasis on radiation hazard could easily cause us to curtail the use of roentgen rays in medicine, in which case medicine as we now know it would disappear. It might cause us to curtail the use of roentgen rays in dentistry. It could cause us to stop radiation therapy and diagnoses with radioactive isotopes. All these things help to make modern medicine truly modern. The neglect of these things would be even more dangerous than underemphasis of radiation safety.

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