Radiation Hazards in Realisti

Radiation protection standards are based on a combination of (1) very limited technical evidence, (2) technical judgment, and (3) selective judgment with regard to matters that are primarily social, political, or economic. There is virtually no information on the deleterious effects of radiation on man at the low levels recommended for radiation workers or for the population in general. These levels represent only a small fraction of the background radiation to which man has always been subjected. Moreover, any disease that can be caused by radiation can occur naturally without there being any necessary distinction as to the origin. Questions such as these, together with a discussion relative to the radiation to which man is normally exposed, were discussed in a lecture given at the International Atomic Energy Agency in Vienna on March 31, 1960, and the present paper is an abridgment of that lecture.

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By ***Lauriston S. Taylor***

THAT radiation in its many forms is of great value to man is not debatable. Similarly, that radiation can be received by man in harmful amounts is not debatable. The question as to whether or not there is some level of radiation exposure below which impairment will not result to man is most decidedly debatable; and, despite the enormous effort that has been directed to this point, there is no essential knowledge today which was not available ten years ago and which will lead to a specific answer to this question. It is therefore assumed with great prudence, *but without proof*, that any unnecessary exposure of man to radiation must be considered as harmful. Again, the degree of harm is completely undefinable for the levels of radiation to which tens of thousands of radiation workers have been exposed for the past several decades; its deleterious effects on the human system are yet to be proven.

Radiation is used today for the protection of health as well as for the promotion of material welfare. As for our health, there is no question but that radiation used in medical diagnosis or therapy has been one of the important factors in the steady increase of our life expectancy. Even in many industrial applications, it is only fair to say that radiation adds another factor to life extension by making possible the nondestructive inspection of the mechanical parts of such things as planes, pipes, automobiles, and other engineering devices, the failure of which could otherwise be costly in terms of lives.

Each use of radiation may entail some avoidable or unavoidable exposure of man to radiation. Thus, radiation can at the same time be a great boon to our health and a possible destroyer of our health. The two concepts are obviously in conflict. A further conflict comes because, as our technology is improved and expanded, the essential, or at least useful, applications of radiation are also expanded. With each new use, and assuming no threshold, the over-all risk to the population is also increased regardless of how small or whether or not any harmful effect can, in fact, be detected.

The problem of reducing or minimizing unnecessary exposure is one that has been under continuous study by the National Committee on Radiation Protection and Measurements (NCRP) and other groups for over 30 years.* Without these efforts our population would, without question, be exposed to much more radiation today than it actually is. The development of radiation exposure criteria has in a sense been largely empirical. This empiricism results from the fact that at any of the occupational exposure levels used for the past 25 years, there is still no reliable information showing a causative relationship between the exposure and injury. Permissible exposure levels for radiation workers have been pushed downward in several successive steps since they were first established in 1934. Each downward step has been dictated by a more acute awareness of the possibility of radiation hazard, and by expanding uses of radiation. Each such step has been compatible with our ability to continue to use the radiation, and has been made possible to a major extent by improvements in our technology and our industrial know-how. Whether the levels of today are sufficiently low or too low is something that cannot be answered solely on the basis of currently available scientific information.

The fact must be recognized that radiation uses entail certain advantages as well as possible harm to man,

* Brief History of the National Committee on Radiation Protection and Measurements (NCRP) covering the period 1929–1946; Health Physics Journal, Vol. 1, pp. 3–10, 1958; Pergamon Press, London, England.
History of the International Commission on Radiological Protection (ICRP), Health Physics Journal, Vol. 1, pp. 97–104, 1958, Pergamon Press, London, England.

rspective

but until the harm can be quantitatively evaluated subjective decisions must be relied upon as to what the acceptable radiation levels must be.

Furthermore, there must be a willingness to accept the fact that certain procedures or operations are so essential to our over-all health and well-being that at the same time there must be willingness to accept some real risk to the person so exposed. One could name many areas outside of the radiation field where such balancing of risk against gain is accepted, in spite of the absence of standards against which either can be measured.

The establishment today of acceptable levels of radiation exposure is filled with many unknowns and uncertainties, the answers to many of which may not be available for decades or generations to come. Pending the development of this information, the NCRP has developed a system of radiation protection standards, or better, protection guides, the use of which has unquestionably been of great value. Where it has been necessary to use balanced judgment in the setting of these protection criteria, the judgment has almost invariably been in the direction of conservatism; that is, in the direction of increased rather than decreased protection. On the other hand, one can argue that leaning always in the direction of conservatism is an admission of the acceptance of a position dominated more by sentiment than by science—this could be a very dangerous position.

In establishing protection criteria, there are two principal types of biomedical damage with which to contend. The first of these is somatic damage or damage to the ordinary body cells of the individual. The other damage is genetic damage or damage to the germ cells, through which hereditary characteristics are passed on from one generation to the next.

Somatic Injury

Somatic damage is limited to the individual whose cells are injured. Here, except for exposures very much larger than permitted occupationally, and very rarely encountered, it has not yet been possible to see a causative relationship between the exposure and the injury. This does not necessarily mean that there has not been an injury. It may be that it is simply not yet known how to observe the injury. The injury may in fact be so obscure as to have mainly an influence on the life span of the individual. However, there is no way of determining whether a specific life shortening is caused by radiation or by any of a thousand other effects which can produce equivalent damage. Life shortening itself is not sharply definable.

Specific radiation effects have yet to be clearly demonstrated in radiation workers exposed for years to radiation levels from 50–500 times that of the background radiation with which they live anyway. But the population of radiation workers is relatively small, probably less than a quarter of one percent of the whole population. If the entire population were exposed to the same levels of radiation, it might be possible by large-scale statistical studies to observe some change in the disease or death rate produced by radiation. Even this is not certain because every disease known to be produced by radiation can also occur naturally from other causes not related to radiation.

Genetic Injury

Genetic damage is much more subtle than somatic damage. For one thing, the damage does not evidence itself in the individual who is exposed. The effects of the original damage come only in succeeding generations and only in a small percentage in each generation. Like somatic damage, the genetic aberrations can also occur for many reasons unrelated to radiation exposure. In fact, it is believed at the present time that only about five percent of the total genetic damage in man is produced by radiation in the natural environment to which he has been exposed throughout time, yet natural background radiation accounts for nearly half of man's exposure from *all sources*.

Genetic damage transmitted through the procreative process naturally becomes more and more difficult to locate in successive generations. It can, therefore, be detected only by very sophisticated statistical means and for this reason, when considering radiation exposure, it is necessary to consider the *average* exposure of the *whole* population rather than the exposure of any given individual. The over-all genetic picture is essentially unaffected by some people having relatively large exposures while others have virtually none at all. Any variations quickly disappear in the normal breeding of man, but it is, of course, important to the offspring of those exposed.

Radiation Exposure Criteria

As pointed out many times over the years, the establishment of radiation protection criteria must, to a considerable extent, be *subjective* until it is possible to detect and understand the effects of very low level exposures such as encountered by radiation workers. On the other hand, many years of experience with radiation workers exposed at permissible levels have failed to show any causative relationships between dose and effect. Present occupational exposure criteria appear to be acceptable, and one has difficulty in seeing any quantitative basis for changing them either upwards or downwards at the present time.

There is considerable experience of a somewhat qualitative nature involving the many radiologists who have unquestionably been exposed to total amounts of whole-body radiation considerably higher than considered acceptable today. They have not suffered any noteworthy deleterious effects, causatively related to their radiation exposure, although there is some evidence for a possible small increase in the incidence of leukemia. It can at least be said that the over-all effects of radiation on radiologists has not been catastrophic.

Maximum permissible exposures for the population-at-large, being set at 1/10 of those for radiation workers, will involve not more than 1/10 of the risk to the individuals in the same age bracket. On the other hand, exposure of the entire population, including those in the childbearing age, to this maximum level might be both somatically and genetically unacceptable, although this remains to be proven.

Up to a point, it may be said that the exposure criteria both for radiation workers and for the population-at-large *are based on observation;* in fact, *they are based on the observation of our present inability to detect deleterious effects.* One cannot, however, accept with complete assurance that this is an entirely satisfactory basis for the establishment of permissible dose levels.

Special Problems of Internal Emitters

The problem of radiation exposure from internal emitters is vastly more complicated and less well understood than exposure from external sources. The basis for the establishment of a permissible dose from internal emitters goes back to the levels chosen for whole-body exposure to external radiation and for which no observable effect has been found. Since the individual cell has no way of distinguishing between the sources of radiation that may damage it, it can probably be said with reasonable assurance that the effects of a given dose would be the same whether from internal or external radiation sources.

The validity of this approach is supported, at least in part, by experience with radium-dial workers, where the radioactive material was deposited in the bone throughout the body. After some study, the original permissible body burden was set at 0.1 μg. The total body burdens of radium have been recently evaluated in some hundreds of persons by various means and it has been established that for amounts less than 0.4 μg there are no observable deleterious effects on the individual. It has also been determined that a total body burden of 0.1 μg will, in fact, deliver a dose twice as large as we consider acceptable from external sources. Thus on the basis of absence of observable effects the external exposure criteria are conservative and, within less than an order of magnitude, are compatible with the internal dose criteria.

The difficulties with the problem of internal exposure arise in the matter of how to measure and control it. For only a few radionuclides is it possible to determine the amount of radioactive material deposited in the body. It is therefore necessary, as in the case of many other industrial hazards, to control the body content by the amount that is allowed to get into the body by one means or another in the first place. In the case of radioactive material, there are many and serious pitfalls lying between the basic requirement of holding the dose to a given permissible level and prescribing the criteria by which the body intake may be controlled.

Assuming that the permissible whole-body exposure, for external radiation is reasonable and acceptable, the first step is to determine the body burden (the amount of radioactive material distributed in the whole body) which will result in the permissible dose level. Theoretically, it is possible, knowing the amount and location of radioactive material in the body, to calculate the dose arising from this foreign material.

A more difficult step is involved in determining how the radioactive material distributes itself in the body after having once entered by means of food, water, and air. A still more difficult step is involved in determining the amount of concentration of material in food, air, or water that will in turn determine the amount that is absorbed by the body. The very definition of a permissible intake involves so many assumptions and uncertainties at the present time that the whole procedure is open to question. It is true that there are many bits of evidence on certain radionuclides in certain physical and biological conditions that contribute to our information on this, but, the total lack is much greater than our total knowledge.

Another large and uncertain step is the translation of a given concentration in air or water to an actual daily or annual intake and retention by the body system. This depends on many physical and physiological factors about which little is known. For example, one factor of possibly great significance, and about which little is known, may have to do with the physical size of the particles of radioactive material that are contained in the intake material. It may well be that radioactive particles of large size may be swept mechanically through the system and be quickly eliminated, whereas, less active particles of much smaller size would be absorbed almost in toto.

It is because of these large uncertainties that pro-

tection committees do not like to see maximum permissible concentrations (MPC) or even maximum permissible doses (MPD) regarded as basic protection criteria which must be rigidly interpreted and enforced. At the very best, MPC's are derived protection criteria containing so many uncertainties as to render them almost meaningless under some circumstances; with existing knowledge, it is almost impossible to say whether they are too high or too low. It is for such reasons that the NCRP has always stressed the need to use an MPD or MPC primarily as a guide, to which must be added a good measure of common sense. Yet at the same time, they have to be accepted in lieu of anything better. The chances are, that if they err, they err on the conservative side. One reason for this is that in each of the successive steps mentioned above, where there has been a choice or a need for the exercise of judgment, the choice has been in the conservative direction. This may have occurred several times throughout the process of calculation and may lead to the very real possibility that the final result has been made grossly over-conservative in some instances. There are probably very few instances where the final result is likely to be seriously under-conservative.

Single-Organ Dose

The problem of determining permissible exposures for single organs has one or two possibly simplifying factors but still contains all of the uncertainties mentioned above. In general, it is reasonable to suppose that if only one organ is exposed, the effect on the whole system will not be as serious as if the whole body including that organ were exposed to the same level. For this reason, the permissible dose for many single organs, is three (or more) times greater than the permissible level for the whole body.

Even here there is a large uncertainty that has to do with the essentiality of a particular organ to the overall functioning of the body. Very little is known as to how damage to any one of the many body organs can influence the whole system. In general, it is probable that the current permissible levels for single organs are substantially more conservative than those for the whole body, but a vast amount of research remains to be done before this can be clearly established.

Chronic vs Acute Exposure—Recovery

There are additional complications with regard to the use of the present-day concept of maximum permissible dose, depending upon whether the exposure to the radiation is distributed over long periods of time at a low level or over rather short periods of time at higher levels; namely, the differences between chronic and acute exposure.

Present day MPD's are designed primarily for occupational exposure conditions, and are calculated on the basis of essentially continuous exposure over a period of approximately 50 years. For short-lived isotopes, the concentrations are calculated in such a way as not to permit the build-up of an equilibrium body burden exceeding the permissible amount. In the case of radionuclides whose life is long in comparison with 50 years, the concentrations are designed so that the maximum permissible body burden and dose rate will not be reached until the end of the 50-year period. This appears to be an obvious inconsistency, but it has not been easy to find a simple way around the difficulty.

Now in any exposure, whether it be chronic or acute, it is reasonable to assume that for somatic damage, there is some element of recovery. Furthermore, on the basis of medical experience, it is reasonable to assume that the chances of recovery are better the lower the total dose. Medical experience also indicates that while there may be substantial recovery, it is never total. In other words, there may always be a small fraction of residual damage.

Currently, it is believed, again on the basis of medical experience, that if a nonlethal, acute exposure is followed by essentially complete absence of exposure, the body will eventually recover all but about 10 percent of its original vitality. Recovery also depends upon the continuity of the exposure. A given dose delivered in successive exposures with intervals between will be followed by more rapid recovery than the same dose delivered in a single exposure. It is also believed that the damage may increase with the dose rate and that hence the ultimate recovery may be somewhat higher from low dose rates than from high dose rates.

From the above discussion, it would appear to be reasonable that exposure of the population at levels 1/10 of those designed for radiation workers may be overly conservative if the public, instead of being continuously exposed, only receives exposures near the permissible levels on occasion or at infrequent intervals.

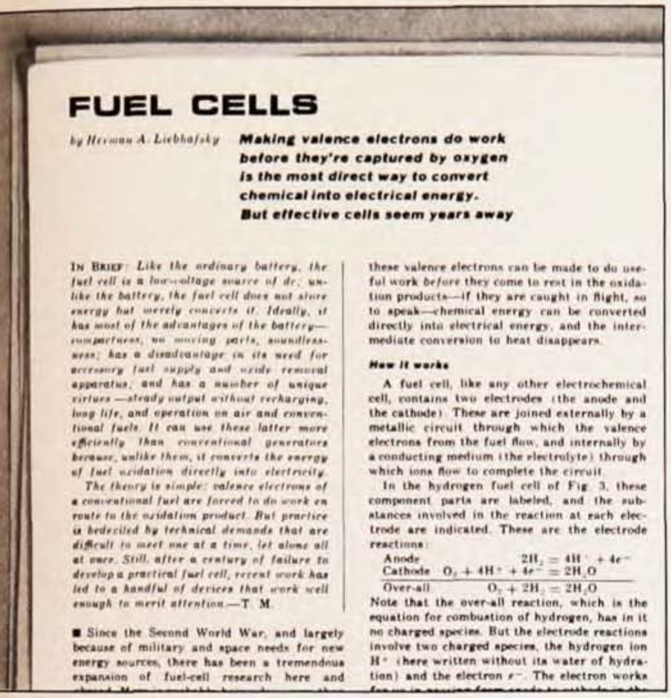
Other well established areas of conservatism have been the assumptions (1) that there is no actual threshold of radiation effect; and (2) that radiation effects are linear with exposure down to zero exposure.* There is no sound proof that either of these assumptions are correct but in absence of positive contrary indications they have been chosen—again in the atmosphere of conservatism.

However, on the basis of the present inability to observe radiation effects for low doses, it is almost necessary to accept the idea that there may be "practical thresholds" to radiation exposure. The present permissible exposures for radiation workers have been set at levels below which no deleterious effects have been observed; therefore, according to all indications the levels are substantially below some "practical threshold". Another example might be in the case of radiation-induced leukemia, for which there appears to be no information at the present time causatively relating a single case of leukemia to an exposure of less than 75 roentgens. For the time being, then, we might accept a practical threshold for leukemia of the order of, say, 50 roent-

* Somatic Radiation Dose for the General Population, Science 131, p. 482–486, February 1960.

IBM asks basic questions in information retrieval

What is known?



FUEL CELLS

by Herman A. Liebhafsky

Making valence electrons do work before they're captured by oxygen is the most direct way to convert chemical into electrical energy. But effective cells seem years away

IN BRIEF: *Like the ordinary battery, the fuel cell is a low-voltage source of dc; unlike the battery, the fuel cell does not store energy but merely converts it. Ideally, it has most of the advantages of the battery—compactness, no moving parts, soundlessness; has a disadvantage in its need for accessory fuel supply and oxide removal apparatus; and has a number of unique virtues—steady output without recharging, long life, and operation on air and conventional fuels. It can use these latter more efficiently than conventional generators because, unlike them, it converts the energy of fuel oxidation directly into electricity.*

The theory is simple: valence electrons of a conventional fuel are forced to do work en route to the oxidation product. But practice is bedeviled by technical demands that are difficult to meet one at a time, let alone all at once. Still, after a century of failure to develop a practical fuel cell, recent work has led to a handful of devices that work well enough to merit attention.—T. M.

■ Since the Second World War, and largely because of military and space needs for new energy sources, there has been a tremendous expansion of fuel-cell research here and

these valence electrons can be made to do useful work *before* they come to rest in the oxidation products—if they are caught in flight, so to speak—chemical energy can be converted directly into electrical energy, and the intermediate conversion to heat disappears.

How it works

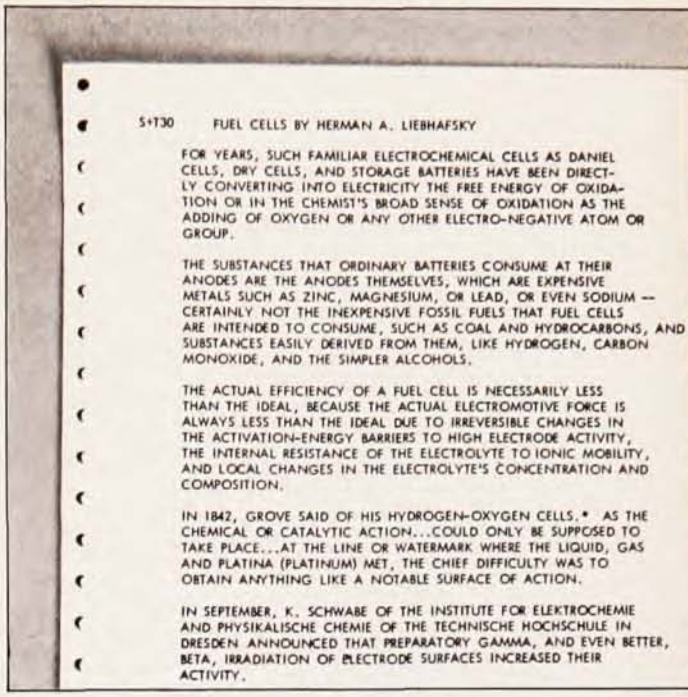
A fuel cell, like any other electrochemical cell, contains two electrodes (the anode and the cathode). These are joined externally by a metallic circuit through which the valence electrons from the fuel flow, and internally by a conducting medium (the electrolyte) through which ions flow to complete the circuit.

In the hydrogen fuel cell of Fig. 3, these component parts are labeled, and the substances involved in the reaction at each electrode are indicated. These are the electrode reactions:

Anode	$2H_2 = 4H^+ + 4e^-$
Cathode	$O_2 + 4H^+ + 4e^- = 2H_2O$
Over-all	$O_2 + 2H_2 = 2H_2O$

Note that the over-all reaction, which is the equation for combustion of hydrogen, has in it no charged species. But the electrode reactions involve two charged species, the hydrogen ion H^+ (here written without its water of hydration) and the electron e^-. The electron works

This 4000-word article appeared in the January, 1962, issue of International Science and Technology. *To abstract the article, a document analyst would read it, define its purpose, and summarize its essential points.*



S+T30 FUEL CELLS BY HERMAN A. LIEBHAFSKY

FOR YEARS, SUCH FAMILIAR ELECTROCHEMICAL CELLS AS DANIEL CELLS, DRY CELLS, AND STORAGE BATTERIES HAVE BEEN DIRECTLY CONVERTING INTO ELECTRICITY THE FREE ENERGY OF OXIDATION OR IN THE CHEMIST'S BROAD SENSE OF OXIDATION AS THE ADDING OF OXYGEN OR ANY OTHER ELECTRO-NEGATIVE ATOM OR GROUP.

THE SUBSTANCES THAT ORDINARY BATTERIES CONSUME AT THEIR ANODES ARE THE ANODES THEMSELVES, WHICH ARE EXPENSIVE METALS SUCH AS ZINC, MAGNESIUM, OR LEAD, OR EVEN SODIUM -- CERTAINLY NOT THE INEXPENSIVE FOSSIL FUELS THAT FUEL CELLS ARE INTENDED TO CONSUME, SUCH AS COAL AND HYDROCARBONS, AND SUBSTANCES EASILY DERIVED FROM THEM, LIKE HYDROGEN, CARBON MONOXIDE, AND THE SIMPLER ALCOHOLS.

THE ACTUAL EFFICIENCY OF A FUEL CELL IS NECESSARILY LESS THAN THE IDEAL, BECAUSE THE ACTUAL ELECTROMOTIVE FORCE IS ALWAYS LESS THAN THE IDEAL DUE TO IRREVERSIBLE CHANGES IN THE ACTIVATION-ENERGY BARRIERS TO HIGH ELECTRODE ACTIVITY, THE INTERNAL RESISTANCE OF THE ELECTROLYTE TO IONIC MOBILITY, AND LOCAL CHANGES IN THE ELECTROLYTE'S CONCENTRATION AND COMPOSITION.

IN 1842, GROVE SAID OF HIS HYDROGEN-OXYGEN CELLS,* AS THE CHEMICAL OR CATALYTIC ACTION...COULD ONLY BE SUPPOSED TO TAKE PLACE...AT THE LINE OR WATERMARK WHERE THE LIQUID, GAS AND PLATINA (PLATINUM) MET, THE CHIEF DIFFICULTY WAS TO OBTAIN ANYTHING LIKE A NOTABLE SURFACE OF ACTION.

IN SEPTEMBER, K. SCHWABE OF THE INSTITUTE FOR ELEKTROCHEMIE AND PHYSIKALISCHE CHEMIE OF THE TECHNISCHE HOCHSCHULE IN DRESDEN ANNOUNCED THAT PREPARATORY GAMMA, AND EVEN BETTER, BETA, IRRADIATION OF ELECTRODE SURFACES INCREASED THEIR ACTIVITY.

This abstract was prepared by an IBM computer. The text was first coded in machine language. The computer then counted key words, and printed out sentences having the greatest statistical significance.

Each year in the physical and life sciences, some 50,000 technical journals will be published throughout the world. 100,000 research reports and 60,000 technical books will also be written. Somewhere in this mass of knowledge may be information you need. To tell what is known—and where to find it—IBM is investigating systems for the dissemination, storage, and retrieval of information.

To create an advanced information retrieval system, labels must be found for *all* useful information in documents. With conventional library indexing, it is difficult to make allowance for new kinds of knowledge. However, computers let us use more versatile methods of indexing. In one of these, the KWIC INDEX (Key Word In Context), a computer selects significant terms in the titles of documents, then prints them out as index entries.

Once indexed, characteristics of documents' contents can be used to notify people of their existence. The Selective Dissemination of Information system at IBM stores profiles describing individuals' interests. A new document's key words are matched against key words in a person's profile. If there is sufficient correlation, he is informed of the document. Profile matching can also be used to retrieve information by storing documents and feeding keyword queries through the system.

At present it is relatively difficult to get text into machine-readable form. However, the development of high-speed optical character readers, automatic language translators, and improved methods of capturing linguistic information at the source may make it possible to introduce information directly into retrieval systems. Once harvested, vast quantities of information will present storage problems. IBM is investigating random-access photostorage systems capable of storing millions of documents and retrieving them in seconds. Out of systems like these may come total information centers which will acquaint scientists and businessmen with all the information needed in their work.

If you have been searching for an opportunity to make important contributions in information retrieval, component engineering, optics, space systems, or any of the other fields in which IBM scientists and engineers are finding answers to basic questions, please contact us. IBM is an Equal Opportunity Employer. Write to: Manager of Professional Employment, IBM Corporation, Department 640S, 590 Madison Avenue, New York 22, New York.

gens. Certainly, if we use such a concept we would not be subjecting the population to any overt insult by setting the permissible exposure criteria so as to assure that their total dose did not exceed this value.

The discussions above relate primarily to damage to the individual. In seeking to control the individual exposure, it is reasonable to set the *maximum* at the practical threshold level. However, to assure that few if any people exceed this maximum, it is desirable to use an *average* value for the whole population which is substantially lower than the maximum.

Comparison of Radiation Exposure Sources

Against the possibility that it may be desirable to regulate the uses of radiation in accordance with the exposure that each gives to the population, it may be of interest to examine some of the radiation sources. Aside from the natural environment, man's radiation exposure may arise from two principal kinds of sources. The first of these might be x rays such as used in medicine, industry, and research; the second would be radionuclides in similar or other applications. X rays are different from other sources of radiation in the important respect that when they are not desired they can be turned off.

Also, a body exposed to radiation from external sources ceases to be irradiated as soon as it or the sources are removed or the source turned off. Radioactive material within the body of course continues to irradiate the tissues until the material either decays to inconsequential levels or is by some means removed from the body.

Since the beginning of time the human system has been exposed to natural sources of radiation arising from cosmic rays, radioactivity in the earth, and radioactivity within the body itself. Moreover, radioactivity within the body gradually increases because of the extremely small but continuous intake that occurs in food, and water. There can be very wide variations in the radiation exposure received from these natural sources. For example, in the Midwest certain essential water supplies contain radium at levels approaching those considered permissible for occupational exposure. There are also areas in the country where the earth has much higher than normal content of radioactive material with a consequent increase in external exposure and probably also an increase in the amount of radioactive material that is taken into the body through the food grown in these areas. In the normal surface soil in the United States, each square mile in a layer 1 foot thick will contain some 3 tons of uranium, 6 tons of thorium, and 1 gram of radium. External exposure from these sources, together with cosmic radiation, contributes some 100 mrem a year to the gonadal dose, while internally deposited material (K^{40}, Ra, C^{14}, etc.) adds about 25 mrem more.

Exposure to radiation varies with altitude because of the increased intensity of the cosmic rays; for example, at an altitude of 5000 feet (Denver, Colo.) the cosmic-ray exposure is about two-and-one-half times that normally received at sea level.

Everyone is exposed to environmental radiation to some degree or another, but in addition, technological advances have led to the introduction of radiation and radiating devices into industry as well as into the home in various forms which cannot be regarded as completely inconsequential.

The following rough tabulation will serve to give a little perspective as to the average gonadal dose to the population from several common sources of radiation. (Some of the figures have been modified since originally presented in 1960.)

Natural background (BG) (Sea level)	125 mrem/yr
Medical procedures	8–48% of BG
Luminous devices (clocks, etc.)	~1%
Shoe fitting machines	> 0.1%
Television receivers	~2%
Fallout	~1.6%
Occupational	~0.4%
Waste	> 0.4%

One must use great caution in using such data, because the various exposures indicated are comparable only for very limited conditions. There is no real basis for comparing the effects of TV radiation with that from K^{40} or Sr^{90} in the body.

These various sources of radiation exposure (and a score of lesser ones not listed) *must* be examined in relation to their importance to our health and well-being —their importance must be questioned.

A listing of essential radiation uses would be more extensive than nonessential radiation uses because of enormous ramifications in the applications of radiation in industry, medicine, and research. Undoubtedly, the most important and essential uses of radiation, either in the form of x rays or radiation from radioactive materials, are in the medical field. Here, if properly and wisely used, x-ray diagnosis and treatment can protect or restore health.

Industrial uses of x rays as well as sealed radionuclides are essential in the nondestructive testing of critical components of machinery and the products of machinery, particularly where the safety of the part is essential to the safety of the user. Industrial uses of x rays probably result in a greater output of radiation than all of the medical uses combined. However, there is a fortunate advantage here in that under most circumstances adequate shields can be constructed so as to maintain the exposure of the workers at extremely low levels.

Apportionment of Radiation Uses

From the preceding discussions, it is not difficult to understand why authorities responsible for radiation control may find themselves thinking about the apportionment of radiation uses or the assignment of quotas for different classes of radiation use. However, there

are severe limitations as to the fraction of man's total exposure that can be apportioned. Natural background must of course be excluded; it amounts to roughly 66 percent of our total exposure as of today.

Medical exposure cannot be assigned a quota; in spite of causing up to about 30 percent of man's exposure, its benefits so far outweigh the concurrent risks, if any, that it must be applied as required. However, there must be a continuing effort to eliminate unnecessary medical exposure and to further improve techniques leading to exposure reduction wherever possible.

The remaining 4 percent of man's exposure today derives from all other man-made radiation sources. In the light of this, arguments for apportionment or the assignment of quotas to different classes of exposure appear to be somewhat academic for the immediate future; this may, of course, change. But, in view of the over-all lack of detailed knowledge about radiation effects, there appears to be little urgency for subdividing and rationing what amounts to only a few percent of the total radiation exposure of the population.

Decisions governing radiation apportionment will be very difficult indeed, and *cannot* be made solely on the basis of scientific information. There will be many political and socio-economic questions that must be decided on the basis of necessity, and a willingness to compensate for possible risk.

If it can be agreed that some amount of radiation exposure is acceptable by the average man, in return for the gains to that average man, assurance must be provided that there is a reasonable relationship between each increment of gain and each increment of exposure. For example, medical uses of radiation alone cannot be allowed to use up all of man's quota of exposure to the exclusion, say of the development of nuclear power. The day will come when nuclear power will be critical to his survival. No more can man be expected to use up his quota through the development of nuclear power to the exclusion of the medical uses of radiation. These two examples possibly represent upper extremes in value.

It will be especially important to scrutinize carefully the obviously less essential uses to determine whether the risk that they entail is worthwhile in comparison with the advantages they provide. For example, it would not appear to be wise to curtail the development of nuclear power in order to have more beautiful but radioactive bathroom tiles.

Today the over-all situation is probably not very bad nor is it likely to become very bad in the lifetime of most of us. On the other hand, we have a deep moral responsibility to make certain that the problem does not become a critical one for those that follow us. We are thus inescapably compelled to consider and, consider carefully, the question of the long-range uses of all radiation sources whatever, to be certain, first, that any level we set is not seriously exceeded, and secondly, to be certain that no one source causes us to use up our exposure allowance at the expense of other uses which may in fact be more essential to our over-all health and well-being.