FUTURE USES OF LARGE RADIATION SOURCES

By Dr. Henry Seligman *

This is a vast subject involving many scientific disciplines - one cannot know everything about it. I shall try to give the reasons why big radiation sources are in the foreground today, how they are made, what they have to do with atomic energy as such, how much power we can get out of them, and - most important - what is being done with them in the different fields. I shall then give a personal preview of how I think future developments will go, and of the benefits which may be obtained.

First of all, let us look at radiation energy as such. We talk of thousands of megawatts of nuclear energy being installed, and we know that for each thousand MW of installed electrical capacity, we inherit every year roughly 3.3 megacuries of caesium 137 and the same amount of strontium 90. This is already a considerable figure because there are thousands of megawatts installed, which means that many millions of curies of caesium and strontium are lying about in ponds or wherever they are being guarded and stored at the moment. This was the first reason for using these big radiation sources - simply because so much radioactive material was produced. At the same time, a parellel development had taken place in the electrical industry. During and after the war that industry had made great progress in developing machines, such as linear accelerators and Van de Graaff machines which can also conveniently be used for massive irradiation.

Let us quickly look at all the sources which are available for this purpose. Obviously the cheapest is the "used fuel element" which comes from every reactor. Indeed, these were the first sources to be used by Atomic Energy establishments needing big radiation sources for development work. To give an idea of how big they are, consider a good research reactor such as a DIDO or a PLUTO. Each fuel element gives out roughly 100,000 curies at the moment when taken out of the reactor. By grouping say, six of these fuel elements around a can with a diameter of 90 cms, one can get something like six million rads ** per hour. This is already a massive dose which can be given in a reasonable time. Of course there are some draw-backs. The source is located at the atomic energy site, and not everyone wants to do his irradiation there. Another disadvantage is that in these fuel rod assemblies the dose rate is not equal, being much higher in the middle than on the outside. This has normally to be rectified by switching fuel elements around, so as to get even distribution. So this is a cheap source — it is available anyhow – but perhaps an inconvenient one to use.

With this type of source, one has to be careful about neutrons, because lanthanum 140 has a fairly high gamma energy, and some six per cent of this

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** *A rad is the basic unit of absorbed dose of radiation.*

gamma energy is above the threshold where interaction takes place with the deuterium in the water. This can result in induced radioactivity.

The next sources to be considered are the fission gases. Xenon 133, one of the fission fragments, is undesirable in a reactor. Xenon is an effective poison, a high neutron absorber. When the Dragon reactor was first conceived, one thought of pumping out the fission products while the reactor was in operation - taking out the fission gases and adsorbing them e.g. on charcoal to provide a cheap and very strong radiation source. This was a possibility but actually another design was preferred.

CHEAP RADIATION

Another possibility is to use loops in reactors. Some reactors are cooled with a sodium-potassium mixture which is a high neutron absorber and becomes highly radioactive. This mixture could then be used outside the reactor as an effective radiation source. A similar way of doing this has been tried in the United States - by using indium salts. These salts - indium also being a high neutron absorber - have been circulated through a reactor, and the resulting gamma energies used. Incidentally, I have a figure on the Hallam reactor, where the sodium coolant has been used. With their arrangement, a radiation dose of 2×10^3 röntgen per hour is obtained. Worked out in money, this is very cheap radiation - 1.2 cents per pound per megarad. This shows again that these sources are economic, if one can bring the material for irradiation to the reactor site.

But as I have said, the biggest sources lying around doing nothing are some of the long-lived fission products like caesium 137 and strontium 90, and a few others. Plants have been erected in several countries to extract them, but unfortunately the process is not very cheap; but the bigger the scale the cheaper. That is to say, if one could separate about a million curies of strontium and caesium at the same time - they are roughly equal in the fission yield - one could get the radiation cheaply, as a simple calculation shows. A chemical plant, which may operate for ten years or so, costs of the order of one, two, or three million dollars. If each year 100 million curies of caesium and strontium are produced, then each curie costs only a very small fraction of a dollar - maybe even less than 1 cent. However, the costs relate not only to the plant but also to encapsulation, and that kind of operation is costly. In addition, the cost must be compared with the cost of the principal competitor, which is at present cobalt 60.

Although cobalt has a half-life of only one-quarter as long as that of caesium, it gives a much stronger gamma radiation, so that it would be necessary to have roughly four times as much caesium to equal the radiation of cobalt. Cobalt 60 is made in a variety of reactors, depending on the flux. There is a whole array of specific activities - varying from two to several hundred curies per gramme - the highest one mainly for medical applications, where the cobalt radiation source is needed in a concentrated form. Cobalt generally makes a nice versatile source which is easy to handle.

Turning to irradiation installations, the irradiation cells of the type first used are relatively simple, however a good deal of gadgetry is necessary for safety. One of the first test plants provided rods containing cobalt, which could be changed in any configuration. They could be made wider, giving bigger volume and smaller radiation dose, and vice versa.

LARGE IRRADIATORS

The use of cobalt has developed with the construction of radiation plants which have been erected in a number of places in the world. One almost loses sight of the cobalt itself, because now the more important and visible part is the gadgetry required for pushing the irradiated material through the plant. The problem here is to make the best use of the radiation which is being emitted for 24 hours a day; this means that all the materials for irradiation have to be handled inside the plant in a certain way. New plants are developed which are more and more automatic, also more expensive, the cost of the cobalt hardly counts any more, because now the main item is the plant with all its safeguards and mechanical parts.

The first such plant to be erected using cobalt was in Australia, built to sterilize goat-hair used in carpet-making, as a precaution against anthrax poisoning. This plant has more than half a million curies of cobalt 60, and has

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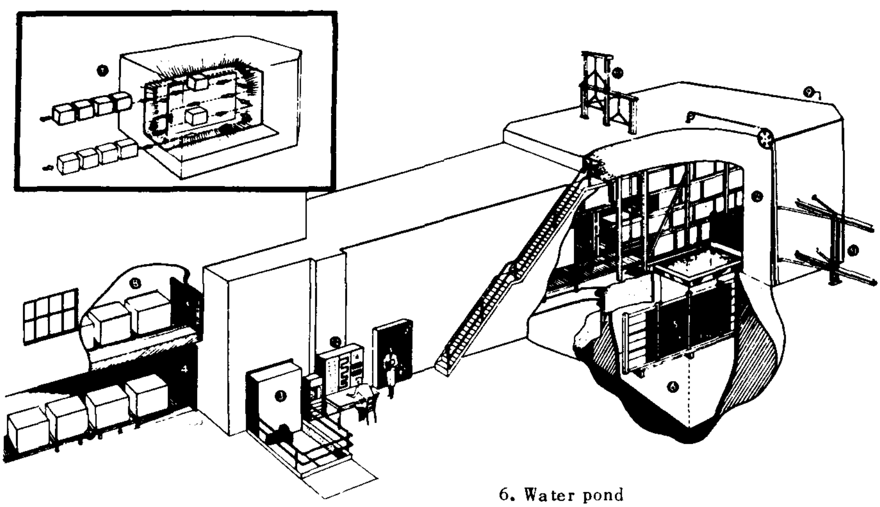
Industrial gamma irradiation plant, which has been in operation in Australia since 1960. The diagram shows the overall design and circulation plan for packages being irradiated.



1. Packages in circulation
2. Concrete irradiation shield
3. Lower shielding door
4. Grille gates
5. Cobalt 60 radiation source in storage position
6. Water pond
7. Input store
8. Output store
9. Hydraulic drives (hidden)
10. Hydraulic lift mechanisms
11. Hydraulic crossfeld mechanisms
12. Control panel

also been used more recently for the irradiation of medical supplies and other purposes.

However, I do not want to discuss all the materials which can be irradiated, but to speak of the development of these big irradiation sources and their exciting possibilities.

The biggest irradiator to my knowledge is in the United States. It is for food irradiation and has a 1.3megacurie source. In the United States a number of foods have been released by the Food and Drug Administration for consumption after certain laid-down irradiation doses.

There are other plants of this type in the United Kingdom - one in Edinburgh and another in the South of England, also for the treatment of medical supplies. But there exist a number of electrical machines. These have some advantages and some disadvantages. It is possible to give a small volume a very high radiation dose within a short time. However, the electrical machines like Van de Graaff machines, have the disadvantage of requiring high voltage with all its breakdown possibilities. The next development was accelerators - mainly linear accelerators - which have also been developed in the same range of a few MeV, from four to twenty-five MeV. Accelerators for these purposes usually go up to 30 kilowatts. In an accelerator irradiation plant one has an even worse problem, as in cobalt plant, which is that of pushing all the boxes - or whatever it may be - through the usually very small irradiation beam.

Lastly, there is a more recent development - the dynamitron. Its main advantage is that it has no large capacity - no large amounts of stored energy - and therefore much lass likelihood of breakdowns. The makers claim that they are more reliable than other machines. They are also made in the range of one to three MeV, and usually between 30 and 100 kW.

RADIATION AND CHEMISTRY

So much for the choice of irradiators at present available. Now we come to the first main subject, where radiation is or can be used beneficially, which is chemistry.

Radiation does change often a chemical compound on impact. One has therefore to do an extensive amount of basic research in the field before - if ever - a new industry will be born called radiation chemistry. The first compounds to be investigated were the polymers, which have the biggest molecules, and for that reason promised to give the highest yield for a given irradiation. The first ones to be investigated were the polyethylenes. What happens with these chain molecules is inter-linking and cross-linking, and this of course makes for even bigger molecules with entirely different physical properties. Different physical properties produced are for example different flexibility and different melting-point. Irradiated polyethylene objects can stand up to temperatures of 120° C, unirradiated, - not. Polyethylene used for ball-point containers is generally irradiated to prevent stress cracking due to the action of the solvent of the ink. This means that many people may have such an irradiated gadget in their pockets without knowing it.

The second example, which is also interesting and currently applied, is the memory effect. Irradiated polyethylene can be deformed and cooled; when re-heated to certain temperatures it reverts to the original shape. This is used for packaging; if one wants to pack something tightly, one can use this memory effect to shrink the package on to the product. If one uses some nice transparent plastic one gets a very nice tight package - you have no doubt seen some commodities packed in this way, and may have wondered how they could be so beautifully packed.

Now we come to something which might have a big future application - the elastomers. These are rubbers which are cross-linked. Vulcanization of rubber is a very touchy subject, because it requires sulphur. The main reason why you have to change your tyres so often is the sulphur in your tyres. So quite early the idea came up of vulcanizing tyres by radiation. But the kind of irradiation required was exceedingly massive - something like 10 megarad. At that time, about 1957-58, we calculated the cost of a reactor constructed solely for a tyre manufacturer, to see whether it would be economic to build a reactor for this purpose only. However, it turned out too expensive. But since then there have been some interesting developments. By adding certain materials one can reduce the necessary irradiation dose from something like 10 million röntgen to 1 million röntgen. Of course assuming that the additives do no more harm to the tyre than the sulphur which one is trying to eliminate by this procedure.

VULCANIZING BY RADIATION

Here you have an indication of the way future developments will go. There are many applications where radiation does not pay at the moment - most of them do not - but they might become economic when some additives are introduced into some of these rather complicated chemical systems in order to reduce the necessary radiation dose and still get the desired effect. Often it is difficult to foresee how these additives will work.

In the literature on the subject, one finds very little; and this is a good sign. If nothing appears in the literature, it means that many companies are working on such projects and keeping it secret. If one reads a lot in the literature about aqueous results and the irradiation of water, one knows that it is generally of little interest to industry. One should scan the literature regularly to see what is missing, which is often the most interesting part. There is very little in the literature about rubber now. That means they must be near some kind of competitive system which brings the radiation dose down still further. I would not be surprised if in a few years one were to find rubber tyres on the market vulcanized with radiation and not with sulphur, which would mean that they would last two to ten times longer than our present tyre. This would be one of the biggest future applications, and reactors might then be built specially for rubber companies. This process might also be done with very big radiation sources, but the tonnage of the tyre manufacturers is so great that they may need special reactors just for that purpose - so we may have not only desalination reactors but for example rubber tyre reactors also.

There are other elastomers such as silicone polymers, which lend themselves very readily to vulcanization because they need a very low radiation dose. Another application which has an effect on the tyre industry is treatment of nylon. Nylon tyre cord has been improved by radiation, and this also may play quite a big part in the future of that industry. Finally, there are the polyvinyl esters, which can be irradiated to make an elastomer, and so one could get an artificial rubber tyre. This has been tried for some time, but it is difficult to judge how far this application has progressed because there are no very detailed publications on this subject.

Normally, irradiation produces some degradation, which is generally not a good thing. But occasionally there are exceptions. For example, dextrane is a very big molecule - too big for blood plasma, but irradiated with exactly the right dose it splits up into exactly the right molecular weight which can be a substitute for blood plasma. This works very well. Conversely, you can build up a monomer to a polymer by irradiation. Starting from a relatively simple compound such as N-vinyl pyrollidone one can built it up until the correct molecular weight is obtained and so make blood substitute in this form. The third method is graft polymerisation, with which one can also obtain molecules of the desired size.

Thus with blood plasma you can do it in three different ways - by degradation, by building up, and by graft polymerisation. Graft polymerisation has important applications too in the paint industry, and there is a whole array of materials which can be irradiated, so that in the future we shall most likely have paints with much better adhesive qualities.

There are other important applications in the oil industry, such as the cracking of hydro-carbons by irradiation.

All these processes can be achieved by using the sources which I have already mentioned. One can use big cobalt sources (except at present for rubber, where you may need complete reactors because of the volume to be processed). But if higher energies are needed, then there is another method - the use of fission fragments. Normal gamma energies are of the order of 1.0, to 1.7 MeV, whereas the energy of the fragments released at the moment when uranium 235 is split, is 162 MeV. One can build chemo-nuclear plants which produce this kind of energy, but it involves very difficult technical problems. Some interesting experiments have been done and some compounds made in this way. I should say that this is still very much in the research stage, but I could well imagine that in the future one could make really good use of the fission fragments in this way.

RADIATION SYNTHESIS

Another important use of radiation is on catalysts; an outstanding example has been a relatively small source of 18.000 curies used to synthesise ethyl bromide from hydrogen bromide and ethylene. A great deal of work has been done on all kinds of bromides, though this to my knowledge is the first industrial process where an organic compound has been synthesised commercially by irradiation.

Let us look in general how chemical synthesis has developed during the last hundred years. It has used mainly variations of temperature and pressure - e.g. vacuum preparation - also electricity (by arcing or by passing a current), and since 1900, catalysts. No other tool has been used; all the million odd compounds are usually synthesised by use of these methods only.

Now here we have an entirely new tool, irradiation, which is different from pressure and temperature. It is not surprising if after ten years of research we are not much further, because radiation does so much on impact. It hits everything, and the energy it hits with is usually much higher than the binding energy in the molecule so that we have to sort out the resulting effects. But it is the first time that we have an entirely new instrument in the preparation of chemical compounds, and that is what makes the prospect exciting. Higher temperatures move your molecules a bit faster; vacuum gives them a longer mean free path. But with radiation one can do entirely different things. Molecules can be split up, cross-linked, combined, free radicals produced and so an entirely new chemistry erected. I foresee a great future for this application - much bigger than the few results which have been achieved so far seem to justify.

Radiation has, of course, a big effect on living beings, and this is being used for certain irradiations of medical supplies. Anything which cannot be easily sterilized with heat because of resulting decomposition, can be sterilized by ultra-violet light (which has been done occasionally, but is usually has insufficient penetration) or by electrons or gamma rays, which penetrate still more and are therefore more useful. Here radiation is not creating a different system - it simply kills. Radiation does not kill everything; when we speak of making something sterile we must be clear about what it implies. For example, if bacteria are irradiated, the number of bacteria is reduced by the same proportion for each time-interval that the object is exposed. That is, after a certain time the number of bacteria is reduced by a tenth, after another certain time by a further tenth, and so on - one never kills the last one. One cannot therefore speak in that sense of "sterility". One reduces the number of bacteria to a certain fraction, and this is a subject for argument among people who use radiation for sterilization - to determine the true situation. That depends very much on the state of the product at the start. If the product is very dirty, say it contains 10^7 bacteria and one reduces it to 10^5, one still has a filthy product at the end. If one starts, as is normal, with only a very few bacteria in the product to be sterilized and then this level is reduced by a factor say, of 10^7, this onviously can safely then be regarded as sterile.

MEDICAL USES

There are firms in different countries which are doing just this. They are sterilizing quite a number of medical products - catheters, syringes, and so on - either by using accelerators, or by means of cobalt sources. An American firm which began this kind of work has switched from accelerators to cobalt sources because they are more reliable. After many experiments, mostly carried out on the most irradiation-resistant bacteria, one found that a dose of 2.5 million electron volts would reduce the number of bacteria by 10^7. In fact, they made tests from the production line before irradiation to see how many bacteria they could count, and found normally very few; this means that on one syringe in a million or five million or something of that sort there might be one.

Other irradiation techniques are used in medicine, such as the grafting of arterial vessels. This has not yet been introduced on a big scale; but bone grafting is more used. It is easy to sterilize bone grafts with radiation, and in one hospital alone, 1,000 patients have had irradiated bone grafts, and in one or two of them some organisms have been found - but these were not organisms which came from the bone grafting. Surgical sutures have been irradiated, and the advantage here is that everything is pre-packed and irradiated afterwards, and so there is no contamination. Then there are a number of pharmaceutical preparations which are difficult to sterilize by heat; they are mainly some of the antibiotics, which stand up to radiation - up to a point. Of course, one has to find out what stands up in the compound and what is adversely affected, and use only those compounds which are not damaged and whose activity is not impaired, while the bacteria are destroyed.

One could say a great deal about agriculture, but I shall only just mention that growth in artichokes, potatoes and onions can be inhibited by irradiation and one can sterilize soil, use irradiation for plant breeding, and there are the possibilities for food preservation. Then there is the destruction of parasites and pests, by irradiation and the sterile male technique.

Thus the future possibilities of irradiation are almost unlimited, whether in chemistry, in medical supplies and preparations, or in agriculture. I personally think that radiation will play a very big role in the elastomers and plastics. I have tried only to give a short survey and to show that this is really an exciting field. We have a new tool, and it is a tool which should bring us very great benefits.