DOSIMETRY AND RADIATION FACILITIES

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Some of the major uses of nuclear radiation in the future will be in the food, drug, plastics, chemical and other industries. This may be for the preservation of foods, for the improvement of properties of plastics, for the vulcanization of rubber, for the promotion of chemical processes or for the sterilization of drugs and hospital supplies.

A few of these applications have al- the use of low-doses of gamma radia- ready reached a commercial level including the use of low-doses of gamma radiation from Cobalt 60 to control sprouting in potatoes in Russia, and the use of higher doses of radiation to sterilize certain medical supplies in the United States.

Before potential applications reach a commercial level, it is necessary to conduct a large number of laboratory studies in order to determine accurately the quantity of radiation or dose required to achieve a desired process and the effect of this radiation dose on the material under treatment. Operations on a pilot scale are required to determine the economic feasibility of a large scale operation, and also to arrive at optimum design features for a production irradiation facility.

Considerations in this paper will be based on gamma radiation—mainly that from Cobalt 60—since machine accelerated electrons are not as suitable for bulk irradiations because of a lower penetrating ability. The description will break into two parts, one part related to the measurement of dose delivered to the product, and the second part to the irradiation facility with which the gamma dose is delivered.

Dosimetry (Dose Measurement)

In the future applications of ionizing radiations for various processes, one very important aspect will be that of accurate measurement of the amount of energy absorbed by the materials under irradiation. With food preservation, for example, the bacteriologist will want to insure that a minimum dose has been delivered to achieve the necessary destruction of micro-organisms and the food technologist will probably not want to exceed a maximum dose above which flavour or texture changes might be unacceptable. Hence, it is desirable to have dose measurements as accurate as possible even though other factors such as the determination and evaluation of the effects of irradiation may not lend themselves to precise measurement.

Dosimetry of Laboratory Irradiation Facilities

In the laboratory facility, one normally has a static condition—that is the source and the material being irradiated do not change their relative position during the actual irradiation. In this case, the dose rate in air for different positions throughout the useful irradiation volume can be measured. Using this map of the gamma field in air, the dose rate in the sample can be deduced from the known absorption properties of the material under irradiation. The exposure time for delivering the required dose can then be calculated for immediate and subsequent irradiations. For subsequent exposure, allowance is made for the decay in the activity of the source which is accurately known at any time following this initial calibration. For example, the activity of Cobalt 60 decays exponentially to half value in a period of 5.3 years. However, errors could arise from mistakes in positioning the sample being irradiated, or in timing the exposure. In such a case, it might be desirable to place individual dosimeters in the package being irradiated to determine with greater accuracy the actual dose delivered. The actual dose in spite of timing or positioning errors would then be measured.

Dosimetry of Production Irradiation Facilities

When we consider, on the other hand, a commercial gamma irradiation facility, the emphasis which is placed on some aspects of dosimetry changes. The cost of dosimetry becomes very important, particularly if the dose delivered to every sample must be measured. In this case a cheap method of dosimetry is indicated. Accuracy also remains important, a minimum dose being required to achieve desired results, but not exceeded by a wide margin since the cost increases with increasing radiation doses.

In a commercial facility, the arrangement will be a dynamic one with the samples moving relative to the gamma source on a conveyor system in order to achieve a high degree of automatic operation and large throughput. In this case, since we are concerned with the integrated dose received by the samples as they move through a changing gamma field, the best method of determining the actual delivered dose is to distribute dosimeters in the samples under irradiation. The effect on the delivered dose of such factors as variations in conveyor speed, self-absorption of the sources, shielding of conveying equipment and of outer layers by inner layers in the case of a multi-pass conveyor arrangement will be included in the measurement obtained by this method. In a dynamic arrangement, the length of exposure can be adjusted by altering the speed of the conveyor to deliver the desired dose.

As experience is gained in the operation of an irradiation facility, the requirement for continued elaborate dose measurement may not be required, in as much as the factors which determine the integrated dose such as belt speed and radiation field are quite predictable.

Requirements for Production Dosimeters

Acuracy and low cost are thus two important requirements for dosimeters to be used in production irradiation facilities.

Other important requirements for a good dosimeter are as follows:

(1) dosimeter measurements should be reproducible, simple and rapid

(2) the dosimeter should be stable after irradiation.

(3) dosimeter readings should be independent of dose rate.

(4) dosimeter readings should be independent of the energy of the radiation.

(5) the dosimeter should measure doses over a wide range from 1,000 rep to 10,000,000 rep if possible.

As for the various systems of dosimetry which might be used, it is convenient to consider three main groups: electrical, chemical and physical.

Electrical

First of all there is the ionization chamber, which is used extensively for measuring the field in air, either as an integrating device or as a rate meter. The principle of operation is to measure the amount of ionization produced by the gamma radiation in a gas-filled cavity. One of the chief limitations in using this method is to obtain an ion chamber which would cover the wide range of dose rates encountered in a large irradiation facility. Ionization chambers are very useful for calibrating other systems of dosimetry and for monitoring the radiation field around irradiation facilities.

Chemical

Another method of dose measurement—chemical dosimetry—is used very extensively at most irradiation facilities. One of the most satisfactory methods is the ferrous-ferric system. In dilute solutions of ferrous sulphate in 0.8N H_2SO_4, the ferrous ions are oxidized to ferric ions under the influence of ionizing radiation. The concentration of ferric ions produced gives a measure of the energy absorbed or the dose. The change in concentration of ferric ions is determined by measuring the change in optical density of the solution using a spectrophotometer. The relationship between dose and optical density is linear up to about 40,000 rep. This dosimeter is independent over a wide range of dose rates, radiation energies and original ferrous ion concentration. This dosimeter is also very stable following irradiation, and has been used to calibrate other systems.

Chemical disimeters are contained in 2 ml. glass ampoules which can be distributed throughout the material under irradiation to determine the actual dose. Two limitations of these chemical methods are that the glass ampoules are fragile and secondly the solution would freeze if distributed in food samples irradiated in a frozen state.

Physical

A third method of dose measurement is glass dosimetry. Glass darkens under irradiation and the change in optical density is a measure of the dose. The relationship between optical density change and dose is linear from about 10^4 rep to 16^6 rep. Glass dosimeters are small pieces of glass, a few mm. thick and about one cm^2 in area. Glass dosimeters have several advantages including chemical inertness, rigidity, small size and permanence. One limitation of glass dosimeters is that they have an enhanced sensitivity at low energies. A second limitation is that the radiation-induced darkening fades following irradiation. Both these restrictions can be easily controlled, however, by proper calibration for a given situation. The silver activated phosphate glass dosimeter can be used repeatedly, since the darkening can be erased with sufficient application of heat. Glass dosimeters thus possess many suitable properties for routine measurements.

The three system of dosimetry are used extensively at most irradiation facilities with the well established ferrous-ferric system finding particularly wide usage on account of its many desirable features. In practice, chemical dosimeters are more suitable for measuring the average integrated dose in a given volume and glass dosimeters are more suitable for mapping in detail the gamma dose rate pattern throughout a volume to obtain information about the maximum and minimum variations from the average for the whole volume.

Irradiation Facilities

An important phase of the Commercial Products Division's work involves the operation and development of gamma radiation facilities. Since most applications of radiation have not been developed to a commercial level, the greatest part of our work, thus far, has involved laboratory scale facilities. In the field of gamma radiation preservation of foods, for example, we have been co-operating with other government establishments in food irradiation studies by supplying irradiation services. In this co-operative program with food specialists from other laboratories, we are endeavouring to study and promote the development of the irradiation process to the stage where this new method becomes commercially feasible.

I will describe the main features of gamma irradiation facilities which we have used or propose to use in our irradiation program involving foods, drugs, plastics, wood products and other materials. These laboratory facilities are the forerunner of the large scale gamma radiation facility, not necessarily in appearance, but in function. The experience we are gaining in irradiating materials on a laboratory scale will be very valuable in the design of future production facilities.

Transfer Case Irradiator

Our first facility comprises one of our transfer cases, that is a lead shielded shipping case, in which there are two drawers. The top drawer contains a Cobalt 60 gamma source which had been used previously for therapy work. The irradiation cavity is located in the other drawer below the source. Samples may be placed in the bottom drawer without exposure to the operator. The dimensions of the irradiation volume are 3"x3"x3", and the dose rate varies from about 400,000 r/hr. at the bottom of the cavity. Provision has been made to rotate samples during irradiation in order to deliver a more uniform dose. This facility has been used for irradiating small samples including seeds, drugs, viruses, plastics, wood products etc.

Spent Fuel Rod Gamma Facility

A second facility is one which uses spent fuel rods from the NRX nuclear reactor—a trench facility. This gamma facility is located in a water filled trench at the Chalk River Project, and hence is not as convenient for us to use. Samples to be irradiated are placed in a water-tight container and lowered between two vertical racks supporting the used fuel rods. This facility can handle much larger samples and has been used for bulk irradiations of potatoes, apples, meats, plastics etc. The dimensions of the present irradiation container are 1' x 1½' x ½', however, much larger volumes could be irradiated if necessary. The dose rate can be varied by changing the separation of the two vertical racks.

A fuel rod facility has several disadvantages in comparison with a Cobalt 60 facility. First of all, the source activity decays rapidly requiring more frequent dosimetric determinations and secondly, there is the inconvenience of having to package the samples in a water-proof container during irradiation. A new fuel rod storage block is anticipated with provision made for irradiating samples in dry holes located between fuel rods stored vertically in cylindrical patterns.

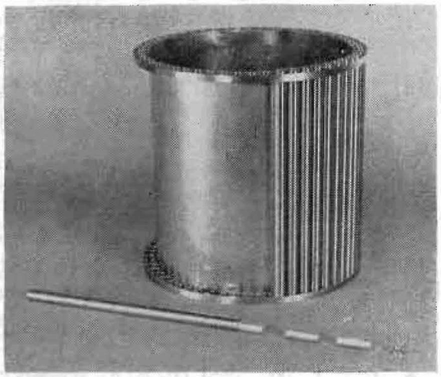
Gammacell "220" Cobalt 60 Irradiator

Our third facility, and one which we are using extensively is a self-contained Cobalt 60 gamma irradiation cell which has been designed by our Engineering Department for laboratory or production use in our own laboratory at Ottawa. This gamma irradiation facility called the "Gammacell 220" will be used for irradiating material for our own experiments and for those of outside laboratories as well. Currently, the facility is being

Cobalt 60 gamma irradiator "Gammacell 220" with built-in shielding can be installed in any laboratory for radiation research. Controls in panel on right permit automatic exposure of samples for pre-set periods to gamma radiation from the shielded Cobalt 60 source. (Photograph — Courtesy, Commercial Products Division, Atomic Energy of Canada Limited.)

used on a 24 hr. basis for irradiating such items as plastics, chemicals, wood products, foods and drugs for our own Division and other departments including the Central Experimental Farm, Food and Drug Directorate, Forest Products Laboratory and the National Research Council.

The irradiation cavity is a cylindrical volume 6" in diameter and 8" in height. Presently the facility contains about 4000 curies of Cobalt 60 with a central field of about 350,000 r/hr.



Source container for Cobalt 60 gamma irradiator "Gammacell 220". The stainless steel cylinder 8" in diameter x 8" in height holds 54 stainless steel sealed rods. Each rod contains 7 radioactive cobalt slugs ¼" diameter x 1" height sealed in 1/16" aluminum jackets. During irradiation, samples are surrounded by the cylindrical array of cobalt 60 pencils, ensuring a gamma field with good uniformity. (Photograph -- Courtesy. Commercial Products Division, Atomic Energy of Canada Ltd.)

Enough shielding has been built into the unit to triple the present activity and hence, increase threefold the resultant field to approximately 1 million r/hr. Samples can be removed automatically after pre-set exposure times up to 120 hrs. using the automatic timer. Provision has been made also for using coolants or heaters around the samples being irradiated.

Since the facility is adequately shielded it can be installed in any laboratory without the requirement for a special shielded room. We have found the facility very convenient to use for our co-operative experiments, since samples can be irradiated minutes after preparation. In addition, irradiations are easily reproducible where it is necessary to repeat a given experiment. Another advantage is that irradiations can be performed without packaging samples in waterproof containers as is necessary with the trench facility.

The effect of increasing doses of gamma radiation on the sprouting of Katahdin potatoes. The tubers are shown after 5½ months storage at 55°F following irradiation. Irradiation doses were as follows: Top left—controls (no irradiation), Top Centre — 1700 rep, Top right — 3400 rep, Bottom Left — 5100 rep, Bottom Centre—6800 rep, Bottom Right—8500 rep. (Photograph — C. Posselwhite, Central Experimental Farm, Ottawa.)

Large Scale Irradiation Facilities

In addition to developing laboratory gamma irradiation facilities, the Commercial Products Division is also considering design proposals for much larger scale facilities. For example, design proposals for a large scale plastic pipe irradiator and a production scale potato irradiator have already been considered by our Division. The proposed potato irradiator would contain some of the following features: capable of handling production quantities; a built-in conveyor system to accommodate bulk or bagged potatoes; convenient to use; designed to deliver a uniform dose and easily moved from one location to another.

As mentioned earlier, both the United States and Russia are in the process of building or already have in operation several large scale gamma irradiators.

The following factors will be important in the design of an irradiator for a particular application: the dose to be received by the material; the range of dose permitted in the material being irradiated i.e., the spread from minimum to maximum dose; the type and size of container or package; the weight limitations if a mobile unit is considered; and the rate of throughput required for a large scale operation.

When considering the economics of a large scale facility, one important factor is the number of hours usage per year. Since gamma sources emit radiation continuously, it is desirable to operate for a maximum number of hours per year in order to keep the processing costs per lb. down to a minimum. If a particular application is seasonal in nature, it would be desirable to find an alternate use for the unit during the off-season.

A second important economic factor in the design of an irradiation facility will be the efficiency of utilization of radiant energy available. The ideal arrangement would be one where 100% of the total available energy is absorbed by the material under irradiation, however, this would be difficult to achieve in practice without exceeding other limitations such as the size of the unit and the weight of the shielding.

The final design will be a compromise of all the above factors, the relative significance attached to each depending on the particular application.

As more applications of radiation are developed in the laboratory or on a pilot plant scale, more specific and detailed designs will be forthcoming for commercial facilities.

(Continued from page 2)

of agricultural products and by-products. This includes efficient use of electric energy for power utilization and control operations, the processing of produce and the conditioning of structures to insure quality control of products.

4. *Soil and Water Conservation Engineering*

This area perhaps more appropriately defined, as management, control, and utilization of water resources, requires engineering in investigating or developing ways to control, manage, and utilize water for the efficient production of crops and the conservation of natural resources.

Since knowledge is the basic ingredient in the engineering operation, limited only in scope by the nature of its application, it must be evident that as new knowledge in the mathematical and physical sciences is made available, that study and experience must be a continuing process in order that this new knowledge may be applied with the best judgment possible to the many complex problems in agriculture, if agricultural engineering is to serve its main purpose in this regard. It must be realized that while the purpose of agricultural engineering in theory does not change, the means by which it is achieved is continually in a state of change or development. Therefore, the challenge in agricultural engineering is:

(1) To gain new knowledge in the sciences.

(2) To study and investigate its potential value in the agricultural field.

(3) Through experience, to apply it with the best judgment possible to either the development of new ways or to methods of improving already established techniques to utilize economically the materials and forces of nature for the problems in agricultural production, processing, transportation, distribution and services.

CORRECTIONS

MacQueen, DOSIMETRY AND RADIATION FACILITIES, P. 6

P. 6 Column 1, - Line 12 should be deleted.

P. 8 Column 1, - Illustration at bottom of page should be inverted.

Hedlin, FRICTION AND SHOCK LOSSES IN SOME AIR-CONVEYING SYSTEMS USED IN AGRICULTURAL APPLICATIONS, P. 15

Eq. 2 should read $\left(\frac{V_1 - V_2}{4005}\right)^2$

Fig. 3 "Head loss, in inches of water, is equal to $\left(\frac{V_1}{4005}\right)^2$"-should be deleted.

Eq. 5 - delete "p"

Eq. 6 - The expression following Eq. 6 should read:

$$F = \frac{1}{m + 1} + \frac{1}{2N} + \frac{m - 1}{6N^2}$$

Eq. 8 should read

$$X_b = \frac{HT}{V.P.b}$$

P. 16, Column 3, Line 11 - "ration" should read "ratio"

P. 16, Column 3, Line 20 should read

--"duct velocity ratios above 0.4. The loss X_b for a takeoff to------"

The angle theta in Fig. 5 is the same as inverted e used in the text.

P. 17 Reference 2 - Kramer instead of Framer
" 8 - Tuve instead of Tauve
" 9 - Christiansen instead of Chrisiansen