



SHIPPING RADIOACTIVE SUBSTANCES

With radioisotope shipments from Oak Ridge alone now running well over three hundred per month, an increase of approximately 500 percent in two years, the need for a comprehensive set of regulations which might be adopted by all carriers was imperative. The National Research Council has worked on the problem of setting up safe standards. The material for this article is taken from a report prepared by Robley D. Evans, the full text of which will be available at a later date from the National Research Council.

In 1936, the manager of a film processing station in Chicago noticed periodic density variations occurring in rolls of 16-mm film sent in by mail for processing. The possibility that these rolls had been irradiated by unprotected shipments of medical radium or radon in the mails was suspected, and inquiry at the Chicago Post Office proved this to be the case.

In 1943, a package containing an unusually strong source of radioactive sodium was carried by a commercial airline from Boston to Rochester, New York. Through an error the parcel was so placed that the pilot was exposed to the radiation from the package.

The first incident led to the exclusion of the entire family of radioactive substances from the mails. The second brought to a halt the informal arrangements which existed for the transport of radioactive materials through the air. (The pilot in question actually received considerably less than the maximum permissible daily radiation exposure.)

There was an obvious need to formulate regulations governing the packaging, stowage, and transportation of radioactive materials. Before this could be done, potential hazards and their control had to

be evaluated quantitatively and before *that* could be done fundamental data on the nuclear properties of radioactive substances and on the interaction of various types of radiation with shielding materials, with photographic materials, with navigation instruments, and with living organisms, had to be compiled. In 1946, about thirty representatives of the Bureau of Explosives, the photographic materials industry, the radium and radon industries, the Express Agency, the American and Canadian railroads, the universities and hospitals, the Air Transport Association, the National Bureau of Standards, the Atomic Energy Commission, the National Research Council, and the National Research Council of Canada met to express their views on the fundamental principles which should underlie a new body of regulations to be enacted by the Interstate Commerce Commission. The final task of drafting a set of regulations was delegated to the Subcommittee on Shipment of Radioactive Substances of the Na-

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The radioisotope container, after being removed from the pile, is transferred to the shipping container (on floor) with a long rod. The radiation exposure level is checked to insure safety during this loading operation.

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tional Research Council's Committee on Nuclear Science.

Basic Principles

From the standpoint of carriers and of film manufacturers, it might be considered ideal if all radioactive materials were so packaged that no detectable radiation escaped the parcel. This is only possible for certain pure alpha ray and beta ray emitters, such as polonium, carbon-14, and sulfur-35, which emit no gamma rays. Substances which emit gamma rays, such as radium, cobalt-60, and sodium-24, cannot be encased in enough lead or other absorbing material to reduce the emergent gamma radiation to just about nothing without making the parcel so heavy and cumbersome that civilian consignees could not afford the shipping charges. There is a reasonable middle ground, where sufficient internal shielding can be used inside the parcel to reduce the emergent gamma radiation to an easily manageable amount. Three principles emerge:

First, there exists a workable compromise between no shielding and gross overshielding in which reasonable protection is granted undeveloped films in transit, and entirely adequate protection is given crew members, passengers, and livestock and plants in transit. To be fair to the shipper, carrier, and consignee of radioactive materials, a small risk must be taken that film may occasionally be slightly affected. It seemed preferable to film manufacturers and users to take this very small calculated risk, rather than to come halfway on the compromise and encase undeveloped films in lead shields.

Second, the magnitude of the risk or hazard due to a particular radioactive parcel depends upon the

amount and nature of the radiation emerging from the parcel, and not on the name of the particular radioactive isotope within the package. For example, the effects of the gamma rays from parcels containing radium, or cobalt-60, or sodium-24, are similar and nearly indistinguishable if the radiation is measured in terms of the ionization which it will produce in air, that is, in roentgen units (with one roentgen equivalent to about 1.6×10^{12} ion pairs per gram of air).

Third, the actual amount and chemical nature of the radioactive substance in the parcel are only of interest and importance if an accident occurs in which the parcel is ruptured and its contents are spilled. Then, if personnel were to ingest or inhale some of the spilled radioactive material accidentally, those chemical elements which are metabolized in such a way that they accumulate and remain fixed in bone, or other tissues or organs, would be more hazardous to people than substances which are not appreciably absorbed by the human system. Among the elements which are readily absorbed and metabolized by the human system, those with a long half-period would offer the greatest hazard, while those with a sufficiently short half-period would be relatively innocuous, even if ingested.

In applying quantity limitations on individual parcels, the chemical nature of the radioactive element is therefore pertinent, and the chemical name of the radioactive element must be declared on the shipping label. However, the regulations take no cognizance of the mode of chemical combination or formulation of this element. This is because the body-metabolism of *all* conceivable compounds is unknown. Hence radium, for example, is regarded

as approximately equally hazardous if ingested as the metal, as the chloride salt, as the sulfate salt, or in any other chemical combination.

Classifications of Radioactive Materials

Radioactive materials are defined as those which spontaneously emit ionizing radiation. Some radioactive isotopes emit only alpha rays, some only beta rays, others emit alpha rays and gamma rays, or beta rays and gamma rays, while still others emit alpha, beta, and gamma rays. With the unique exception of samarium, the alpha ray emitting substances are all elements of high atomic weight belonging to the uranium, thorium, actinium, or neptunium family of radioactive elements.

The artificially radioactive isotopes are mostly beta ray emitters, together with a smaller number which decay by electron capture. Some of these beta ray and electron-capture disintegrations are accompanied by nuclear gamma rays, others are not. In all beta ray and all electron-capture transitions, about one percent or less of the available energy is emitted in continuous x-rays, or "inner bremsstrahlung." In addition, the absorption of beta rays by matter always causes the production of a small amount of both characteristic and continuous x-rays, or "outer bremsstrahlung," from the absorbing material.

Thus even those isotopes which emit no true gamma rays (i.e., electromagnetic radiation originating in the nucleus) will all emit some x-rays (i.e., electromagnetic radiation originating outside the nucleus). All electron-capture transitions are accompanied by characteristic x-rays of the decay product; for example, iron-55 emits no nuclear gamma rays,

and the only radiations reported from this electron-capture radioactivity are the characteristic x-rays of the stable decay product, manganese-55, and a very feeble inner bremsstrahlung corresponding to five quanta per million disintegrations and having a maximum energy of 0.15 Mev.

In the shipping regulations, the expression "gamma rays" is used to connote a significant amount of electromagnetic radiation without respect to its origin, and thus includes x-rays following electron capture, as well as both inner and outer bremsstrahlung, provided these radiations are sufficiently intense to be significant at the outer surface of the finished parcel. By "significant" is meant at least 10 milliroentgens (mr) per 24 hours.

In terms of the type of radiation emitted, all radioactive materials are classified into three groups. In the first group are the gamma ray emitters. If at any time during transportation the gamma ray (including x-ray) intensity at any surface of the finished package will exceed 10 milliroentgens per 24 hours, the radioactive material is classified as Group I.

The second group includes neutron sources. All the known radioactive isotopes which spontaneously emit neutrons have half-periods which are shorter than one minute. Neutron-emitting sources offered for transportation will therefore be mixtures such as are typified by radium and beryllium. In general, a reasonably long-lived radioactive source of alpha rays is mixed with beryllium or boron, or a source of high-energy gamma rays is mixed with deuterium or beryllium. Neutrons are produced by nuclear disintegration under the continued bombardment by alpha rays or gamma rays emitted by the radioactive constituent within the neutron source. Any artificial

Radioisotopes being loaded into shipping containers. The health physicist is measuring the surface radiation of each container to make certain that it does not exceed the permissible limit. As a final precaution filter paper will be rubbed over the surface of the sealed containers and will be monitored to make certain there is no residual contamination.

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neutron source will also emit gamma radiation, and the neutron flux emerging from the surface of the package will, of course, cause ionization only by producing secondary rays such as knock-on protons. The number of neutron sources offered from transportation is expected to be very small.

Radioactive material with negligible external radiation is classified as Group III. This group includes all isotopes which emit negligible nuclear gamma radiation, provided that the secondary x-rays produce less than 10 milliroentgens in 24 hours at the surface of the finished parcel.

Regulations

Now that radioactive substances have become so important in the daily life of the nation, particularly in medical, scientific, and industrial activities, the actual and potential traffic volume of radioactive substances is no longer negligible. The U. S. Post Office has recently revised the postal regulations governing radioactive substances to admit to the mails those parcels of radioactive materials which have a surface radiation of less than 10 milliroentgens in 24 hours and are otherwise exempt from specification packaging and labeling under ICC regulations. However, it is to be noted that whenever a frankly radioactive substance is to be shipped by mail a label and a safe design and preparation of the package are required.

Some of the Interstate Commerce Commission packaging and labeling regulations for shipments

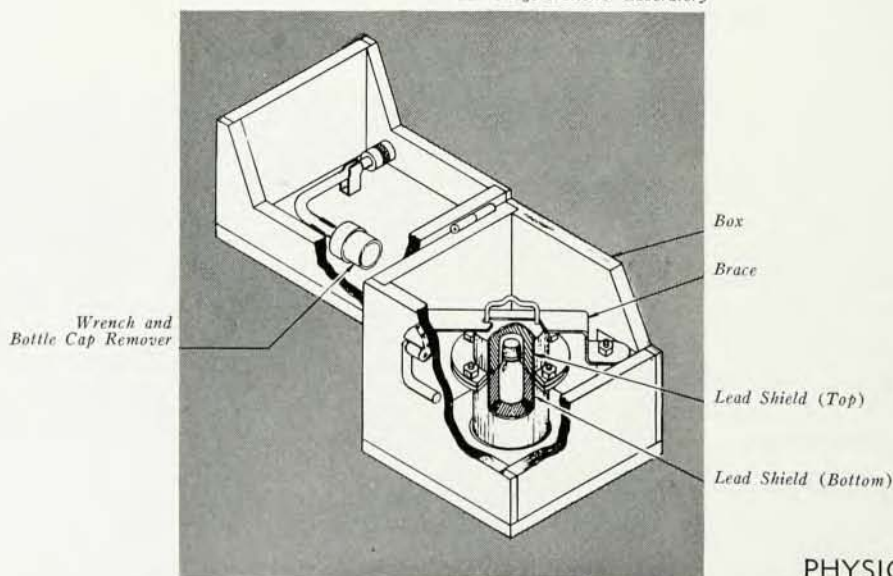
by express are summarized in the accompanying table. The full text of these regulations may be obtained from the Bureau of Explosives, 30 Vesey Street, New York 7, N. Y.

The highly perishable character of many short-lived radioactive isotopes requires that they be transported by air if they are to be successfully used at any distance from their point of manufacture. The Civil Aeronautics Board has very recently passed new regulations governing the air transport by air express of radioactive substances. These regulations adopt in entirety the ICC ground regulations for packing, marking, and labeling. They specify how and where the radioactive parcels are to be stowed aboard the airplane for the complete protection of crew, passengers, and air express shipments of photographic materials. Passengers' luggage, mail, and unidentified cargo on scheduled airlines will be afforded the same protection (separation) as crew members.

Shipments which must travel by two or more carriers (air, water, truck, or rail; mail, express, or freight) are expedited by these uniform packaging and labeling regulations adopted by the Interstate Commerce Commission, by the Civil Aeronautics Board, and the United States Post Office Department. Foreign shipments are also being expedited through the development abroad of regulations which are in harmony with these American regulations. Regulations governing rail express and freight which are identical with the American regulations have already been adopted in Canada.

THE NEWEST TYPE RETURNABLE CONTAINER

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SUMMARY OF INTERSTATE COMMERCE COMMISSION PACKAGING AND LABELING REGULATIONS

All finished packages must:

1. have no dimension smaller than four inches;
2. have such a construction that the external gamma radiation is not more than 200 mr/hr at any point of the readily accessible surface;
3. have internal shielding sufficient to absorb all primary alpha and beta radiation from the source;
4. have sufficient internal shielding so that the gamma radiation at a distance of one meter from the finished package does not exceed 10 mr/hr.

If the radioactive substance is a *liquid*, packed in a breakable inner container, this container must be surrounded by a sufficient amount of absorbent material to absorb the entire liquid contents. This liquid-absorbing material must be inside any gamma ray shields and must be of such type that its efficiency will not be impaired by chemical reaction with the liquid contents.

Substances such as radium, plutonium, and strontium, must be enclosed within a strong inside metal container, consisting of a stainless steel, malleable iron, or brass tube, with a screw-type enclosure. The tube may be up to 8 in. long, and 3 in. in dia.; minimum wall thickness $\frac{3}{32}$ in. for diameters up to 2 in., and $\frac{1}{8}$ in. for diameters up to 3 in.

The maximum content which may be packed in one outside container is 2,000 millicuries of radium, polonium, or other members of the uranium-238-radium-226 family; or for any other radioactive substance, that amount which disintegrates at the rate of 10^{11} atoms per second ($= 10^5$ rd ≈ 2700 mc). 1 millicurie (mc) is defined as being equal to 37×10^6 disintegrating atoms per second. 1 rutherford (rd) is defined as being equal to 10^6 disintegrating atoms per second.

Labeling:

1. Group I (gamma ray emitters) and Group II (neutron emitters) radioactive substances must contain on the outside of the package a distinctive red-on-white label which describes the contents.
2. Group III substances must contain on the outside of the package a distinctive blue-on-white label which names the contents.

SHIPMENTS EXEMPT FROM REGULATIONS

Package strength:

1. Strong enough to prevent leakage of radioactive material.

Quantity limitation:

1. Total activity must not exceed 0.1 mc for radium or polonium; 5×10^6 disintegrations per second ($= 5$ rd ≈ 0.135 mc) for Sr^{90} , Sr^{90} , or Ba^{140} ; or 50×10^6 disintegrations per second ($= 50$ rd ≈ 1.35 mc) for any other radioactive substance.

Surface radiation limitations:

1. No significant alpha or beta radiation emitted by completed package.
2. Gamma radiation from any surface of the parcel must not exceed 0.4 mr per hr ($= 10$ mr/24 hr).
3. No significant neutron radiation emitted by the package.

If the package contains only self-luminous compounds, or manufactured articles (except liquids) containing radioactive materials, the quantity limitation above does not apply.