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TECHNICAL PROGRESS REVIEW

ISOTOPES AND RADIATION TECHNOLOGY

VOLUME 1, NO. 1

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TECHNICAL PROGRESS REVIEW
ISOTOPES AND RADIATION TECHNOLOGY

VOLUME 1, NO. 1

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A new Quarterly Technical Progress Review, "Isotopes and Radiation Technolgoy," was approved by the U. S. Atomic Energy Commission in the summer of 1962 and its preparation was assigned to ORNL as a part of the general program of the Isotopes Development Center. The assembly of a staff began almost immediately. By early fall, under the auspices of the AEC's Divisions of Technical Information and Isotopes Development, the preliminary drafts which are now the first issue of this periodical were being developed. "Isotopes and Radiation Technology" is the fifth of a series of Commission-sponsored quarterly technical progress reviews which cover broadly the field of nuclear science and technology. The others are Nuclear Safety, Power Reactor Technology, Reactor Materials, and Reactor Fuel Processing.

This new review will emphasize the reporting of DID-sponsored research and development. By publicizing present applications, it can help to expand the utilization of isotopes; and by helping the Commission and contractors to keep abreast of related activities within the AEC complex it can help prevent overlap of research effort and can aid in predicting isotope usage so as to point the direction for future isotope production efforts.

"Isotopes and Radiation Technology" is a technical progress review. Even guest articles will be of a review nature.* The editors and the AEC have no intention of duplicating the present efforts of commercial publishers of abstract journals and periodicals covering original research, and overlapping will be avoided. Books, monographs, and bibliographies that are considered pertinent to the areas routinely covered will be noted and occasionally reviewed.

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*e.g., see report by G. H. Cartledge on technetium in this issue, p. 3.

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TECHNICAL PROGRESS REVIEW

Isotopes and Radiation Technology

VII. APPLICATIONS IN MEDICINE

The literature on medical uses of radioisotopes is briefly reviewed here.* Since developments in this rapidly expanding field have been summarized in various well-documented publications,[1] earlier original literature was not extensively consulted. Only a few of the many published papers are listed here, and emphasis is on recent, rather than older, work. Since many reports are preliminary and opinions on the effectiveness of some of the isotopes differ widely, in future issues of this quarterly various viewpoints on the medical use of radioisotopes will be presented, and some of the less well-known isotopes, both old and new, will be reviewed. Readers with publications in this field are invited to send in reprints to ensure coverage.

The medical use of artificial radioactive isotopes began in the late thirties.[2] The increasing interest in them is indicated by the numerous conferences,[3] journals,[4] bibliographies,[5] and reviews[6] partly or entirely devoted to this field. Radioisotopes are used in both diagnosis and therapy (Table VII-1[7]), in the former in extremely small amounts; in the latter, chiefly in malignant or malignancy-related conditions. Safety in their use is ensured (1) by requiring the licensing of physicians who use them -- and then only after special training; (2) by standardization of handling techniques and adoption of special safety regulations by hospitals.[8] Early fears of long-term adverse

*The editors of this review gratefully acknowledge the many helpful suggestions made by W. G. Myers, M.D., and M. Brucer, M.D., who reviewed a rough draft of the manuscript. Some of their suggestions that could not be readily incorporated will be used in future issues.

Table VII-1. Radioisotopes Used in Diagnosis and Therapy*

Diagnosis		
Test	Measurement	Usefulness
I^{131} studies of thyroid function; NaI, usually oral	Percentage of dose concentrated in thyroid, percentage of dose excreted in urine; plasma free and bound I^{131}	Valuable index of thyroid function; drugs cause interference
I^{131} for diagnosis of thyroid carcinoma; oral	Scanning and external procedures	Relatively little value while normal thyroid gland present; highly useful in locating well differentiated metastatic lesions after thyroidectomy
Fe^{59} iron metabolism; usually intravenous iron citrate; oral doses used to study absorption	Serial plasma assays for several hours; red cell assays for about 10 days; external counts over spleen, liver, sacrum; blood and fecal assays after oral dose	Helps explain mechanism of some anemias, importance of impaired erythropoiesis versus hemolysis; oral test indicates absorption defects.
Cr^{51} red cell survival; red cells labeled with Cr^{51} in vitro and injected intravenously	Serial assays of blood (red cells) for 2 or 3 weeks; external counts over spleen, liver, heart; fecal assays for gastrointestinal bleeding	Indicates rate of hemolysis and to some extent the role of the spleen in hemolysis
Co^{60}-vitamin B_{12}; oral	Fecal and urinary excretion; sometimes external counts over liver	Shows fundamental defect of pernicious anemia even if patient is not in hematologic relapse
I^{131}-labeled rose bengal; intravenous	Rates of removal from bloodstream and concentration in liver	An index of liver function and biliary patency

Table VII-1. Contd.

Test	Measurement	Usefulness
I^{131}-labeled fat; oral	Blood, urinary, and fecal levels	Information on intestinal absorption, pancreatic function
Cr^{51}, P^{32} red cell mass; I^{131} albumin-plasma volume, Na^{24}, K^{42} for Na and K spaces	All based on dilution principle; solution of isotope (or suspension of red cells tagged in vitro) given intravenously and after mixing in the body, blood concentration determined	These tests give data on red cell and plasma volumes, fluid balance and electrolyte status; may be helpful in presurgical evaluation, study of metabolic and endocrine disorders.

Therapy

	Patients Treated	Usefulness
I^{131} as NaI; usually oral	Uncomplicated Graves' disease patients over 40; complicated Graves' disease any age	General results excellent; multiple doses needed in some cases; significant incidence of early or delayed myxedema
	Toxic nodular goiter in selected patients	Eventual control of toxicity in most cases; may require repeated doses; concern over malignancy already present at onset, plus desire for rapid result, may recommend surgery for patients who can be well prepared

Table VII-1. Contd.

	Patients Treated	Usefulness
	Thyroid carcinoma in selected patients	For treatment of relatively small group of patients with nonresectable lesions showing ability to concentrate the isotope
	Certain patients with angina pectoris or intractable congestive heart failure	Clinical improvement in significant percentage
P^{32} as soluble phosphate; oral or intravenous	Chronic granulocytic leukemia	Generally good results
	Chronic lymphocytic leukemia	Useful, often in conjunction with local irradiation
	Polycythemia vera	Good results in patients not suitable for phlebotomy alone
	Lymphosarcoma, multiple myeloma, diffuse bone metastases	Occasionally some value
	Acute leukemia, Hodgkin's disease	Rarely useful
Colloidal Au^{198}, P^{32}, Y^{90}	Intracavitary in patients with effusions and ascites caused by malignant tumors	Symptomatic value; partially supplanted by nitrogen mustards
	Intravenous for granulocytic leukemia and diffuse lymphoma of liver	Very limited value compared with other forms of therapy

Table VII-1. Contd.

	Patients Treated	Usefulness
	Direct injection into tumor in certain cases of prostate carcinoma; attempt to radiate lymphatic channels	Believed useful if properly used in carefully selected cases
Co^{60}, Cs^{137}, radium-226, radon-222, Sr^{90} for implantation and brachytherapy	Certain localized tumors, especially carcinoma of cervix, head, and neck	Useful in skilled hands for properly selected patients
Co^{60}, Cs^{137} for teletherapy	For all lesions suitable for external radiation therapy	Highly useful and practical

*Reprinted with minor style changes with the kind permission of publishers, from G. A. Andrews, Medical students and radioisotopes, The New Physician, 9(12):23-7 (1960).

effects on patients have been tempered by the results of experience. According to Lawrence,[9] for example, cancer has not once been reported as a result of radioactive iodine therapy of thousands of hyperthyroid patients; and in 25 years, the survival rate of more than 500 polycythemia vera patients treated with P^{32} has been about the same as that of patients with diabetes or pernicious anemia treated by standard methods. There is wide usage of radioactive iodine for toxic goiter in patients over 45, of P^{32} for polycythemia vera, and of various isotopes for pituitary or thyroid ablations to relieve other conditions.[1]

Among the radioisotopes now used in internal medicine in the largest amounts are I^{131}, P^{32}, Au^{198}, Cr^{51}, Fe^{59}, and Hg^{203}, but many others are used in smaller amounts; large quantities of Co^{60} and Cs^{137} are used in teletherapy units. Many radioisotopes are being studied for potential use, and useful ones are introduced into the field as new production methods are developed and costs are lowered. Criteria for suitable isotopes include high specific activity, suitable half-life, physiological compatibility with body processes, and the ability to at least partially localize in the tissue being examined or treated. Radioiodine, for example, while not entirely thyroid-specific, is an obvious choice for thyroid conditions, as is calcium for bone. Specificity may sometimes be obtained by incorporation in compounds (e.g., radiocobalt in vitamin B_{12}, which localizes in the liver). An isotope may be localized physically as a wire, as a colloid, or as the recently introduced ceramic beads.[10] Both the physiological and biological half-life must be considered, and selection may be made on the basis of the need for particular radiation characteristics -- from a soft beta all the way to a hard gamma radiation. In earlier work, isotopes with a short physical half-life were found inconvenient to use,[11] but they are finding application now with development of new instrumentation and sources of supply.

Iodine

I^{131} (8.1 d, 0.33- and 0.61-Mev β's, 0.36- and 0.64-Mev γ's). Iodine-131 is most commonly used for diagnosis of thyroid disorders.[1] Other uses include incorporation in human serum albumin for determination of the total circulating plasma volume, placentography,[12] estimation of mitral valve size,[13] and detection of right-to-left cardiac shunts. There has been partial success in localizing brain tumors with I^{131}-labeled compounds, and I^{131}-labeled methyl iodide has been used for detecting left-to-right cardiac shunts.[14] Rose Bengal containing I^{131} is useful for liver function tests and for blood flow tests[15] and has been suggested for detecting liver metastases that are not obvious from surgery.[16] Recent reports indicate the Rose Bengal-I^{131} hepatoscan to be a satisfactory technique.[17] Other I^{131}-labeled compounds reported useful are Hippuran for renal tests[18] and for determining cerebral circulation time;[19] Diodrast for evaluating venous diseases of the lower extremities;[20] sulfobromophthalein for liver function tests;[21] and compounds for studying fat metabolism.[22] An I^{131}-labeled compound demonstrated 200-ml pericardial effusions in a simulated system,[23] and an accurate and reproducible method for insulin assay with I^{131} has been reported.[24]

In therapy, I^{131} has been used for nontoxic[25] as well as toxic goiter.[1] It is used as a palliative in thyroid carcinoma, and an

I^{131}-tagged fat-soluble medium, which accumulates in regional lymph nodes, is potentially useful for irradiation of neoplasms.[26] Thyroid ablation by I^{131} in more than 1000 patients improved angina pectoris in 75% and congestive heart failure in 60% of those afflicted.[27] Fortunately, gamma irradiation of the ovaries from urinary excretion of administered I^{131} is considered negligible.[28]

I^{125} (57.4 d, no β, 0.035-Mev γ). Iodine-125*, which is easily produced by neutron bombardment of Xe^{124}, is becoming increasingly valuable in diagnosis. Irradiation of a patient by it is about half[29] that from I^{131}, assuming that the biological half time is equal to the physical half-life. Good thyroid and liver scans have been made with it,[30] and Hippuran labeled with I^{125} has been used for renograms.[31] As a tag for serum albumin and oleic acid and in the salt NaI^{125}, it has given good results in experimental blood volume, absorption, and thyroid tests,[32] and has been suggested for indicating the extent of arteriosclerosis.[33] In a promising new technique for lipid digestion and absorption studies, a compound labeled with I^{131} and another labeled with I^{125} are administered simultaneously.[34] The promising use of I^{125} in radiography[35] is indicated by a photograph of the bones of a hand made with this isotope (Fig. R3, R4). Exposure to both patient and technician is low because of the ease of shielding against the 27.2 and 35.4-kev photons. Portable x-ray equipment is being developed with I^{125} sources.[36]

I^{132} (2.3 hr, 1.5- to 2.1-Mev β's, 0.53- to 0.95-Mev γ's). The use of I^{132}, which is easily recovered from a tellurium source, would decrease patient exposure to 1-2% of that from I^{131} and would

*See also p. 245.

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allow repeated administration.[37] Thyroid function after I^{131} therapy may be determined by observing the absorption of I^{132}, whose higher energy gammas are easily detected in the presence of residual I^{131}.[38]

I^{123} (13.3 hr, no β, 0.16-Mev γ). With I^{123}, exposure of a patient would be only 1-5% of that from I^{131}. Experiments on preparation of curie amounts are projected.[39]

I^{124} (4 d, 1.53- and 2.13-Mev β's, 0.6- and 1.72-Mev γ's). Iodine-124 has been suggested for greater uniformity of dose in thyroid carcinoma.[40]

Phosphorus

P^{32} (14.3 d, 1.71-Mev β, no γ). The largest use of P^{32} is in treatment of polycythemia vera and chronic leukemia.[1] It has not been very useful in acute leukemia. Blotting paper soaked with radioactive sodium phosphate was used in early applications for skin lesions, and activated red phosphorus incorporated in polyethylene in later work. Metastatic bone cancer has been treated with P^{32} as the phosphate.[41]

Colloidal chromic phosphate-P^{32} and Au^{198}, as well as nitrogen mustard, for control of malignant intracavity effusions are compared in a recent review[42] of 222 cases treated with P^{32} and 2110 with Au^{198}. Colloidal chromic phosphate-P^{32} has been used for palliation of cancer, and colloidal zirconyl phosphate-P^{32} administered intravenously to more than 250 patients with chronic leukemia and lymphomas is reported to have resulted in prolonged remissions and long treatment-free periods.[43]

In diagnostic applications, an in vivo test for human spermatogenesis using sodium phosphate-P^{32} has been described,[44] and the ability of newly proliferating cells to concentrate P^{32} has been used to differentiate benign from malignant ocular lesions.[45]

Gold

Au^{198} (2.7 d, 0.97-Mev β, 0.41-Mev γ). Gold-198 is most commonly used as a colloid,[1] which has 0.003- to 0.007-μ-dia. particles. When this material is administered to a patient and a scan is performed, normal liver shows an even gradation of activity, but lesions result in activity concentrations.[46] Diagnostic uses include determination of liver blood flow,[15] and in regions where the parasitic Taenia *Echinococcus granulosus* occurs it has been used for localizing hydatid liver cysts and for following up healing after drug administration or surgery.[47]

Colloidal gold has been used in treating both primary carcinoma and metastases.[48] Transportation to the lymph nodes is hastened if the particles are coated with silver,[49] but radioactive colloidal gold has been injected directly into the lymphatics.[50] Other uses are in treating leukemia[51] and in controlling malignancy-induced intracavity fluids.[52]

Interstitial implants of Au^{198} seeds have been used for hypophysectomy and for palliation of metastatic carcinoma.[53] The hypophysis implantation requires about 30 min. Problems in surgical and radiotherapeutic pituitary ablation are discussed in recent reviews.[54]

Chromium

Cr^{51} (28 d, no β, 0.32-Mev γ). Hexapositive Cr^{51}, in $Na_2Cr^{51}O_4$, attaches to the red cells and may be used to determine such quantities as red cell survival time.[1] A new instrument for accurate blood volume measurement uses Cr^{51}-tagged red cells or I^{131}-albumin.[55] Such cells have been suggested for determination of cardiac output and for placental localization (no activity is transferred to the fetal circulation), and are the basis for a simple method for quantitation of menstrual blood loss[56] and for spleen studies.[57] Tripositive chromium (as $Cr^{51}Cl_3$) in solution attaches to plasma proteins and is useful for determining plasma volume. Serum albumin labeled with Cr^{51} is easily prepared and has been introduced for demonstrating gastrointestinal protein loss.[58]

Implants of Cr^{51} have been recommended for cancer therapy.[59]

Iron

Fe^{59} (45 d, 0.26- and 0.46-Mev β, 1.1- and 1.3-Mev γ). Detailed methods for Fe^{59} tests are described in a recent brochure.[60] As the chloride, citrate, or sulfate, Fe^{59} has been used for iron absorption and utilization studies.[61] It has also been used for determining red cell survival time, but the necessity of labeling the cells in vitro makes it less convenient than Cr^{51}. The advantages and disadvantages of Fe^{59} and Cr^{51} are discussed in a recent review.[62]

Fe^{55} (2.94 y, 0.0059-Mev x ray following electron capture). Comparison of the percentage utilization of intravenously administered Fe^{59} to that of oral Fe^{55} has been used for iron absorption studies.[63]

Mercury

Hg^{203} (47 d, 0.21-Mev β, 0.28-Mev γ). Besides the use of mercury isotopes in tracing kidney drugs,[64] Hg^{203} has been used for localizing brain tumors and for determining cerebral circulation time.[65] Neohydrin and Chlormerodrin labeled with Hg^{203} have been used for kidney examinations.[66]

Boron

B^{10}. When the stable isotope B^{10} is deposited in brain tumor tissue and activated by neutron bombardment, the released alpha radiation is effective for control and palliation.[67] By this treatment, cells of transplantable sarcomas in mice have been killed and cancer has disappeared in 2-4 weeks.[68] This method of treatment is not new, but basic techniques are still being investigated.[69]

Fluorine

F^{18} (1.87 hr, 0.65-Mev positron emission). Fluorine-18 has been used as a replacement for Ca^{47} and Sr^{85} in bone scanning.[70] It has also found application in thyroid studies[71] and in locating brain tumors.[72]

Selenium

Se^{75} (120 d, no β, 0.14- to 0.28-Mev γ's). The high specificity of Se^{75}-selenomethionine for the pancreas suggests that this compound might be useful in early detection of pancreas carcinoma.[73]

Krypton

Kr^{85} (10.6 y, 0.67-Mev β). Because of its low solubility, injected or inhaled Kr^{85} is useful in determining cerebral and coronary blood flow and cardiac and pulmonary shunts.[74] For example, if a right-to-left cardiac shunt is present, activity in the arterial system rises rapidly when Kr^{85} is given intravenously.[75] If a left-to-right shunt is present, the Kr^{85} concentration in the pulmonary artery reaches a value 20 times that in a systemic artery following inhalation of this gas.[76] A simple technique for studying pulmonary function with Kr^{85} has been devised,[77] and a new technique for rapid and accurate measurements of serial heart blood flow was reported recently.[78]

Strontium and Yttrium

Sr^{90} (28 y, 0.54-Mev β, 2.27-Mev β from Y^{90} daughter, no γ). In an external source containing Sr^{90} designed for use in ophthalmology, the Sr^{90} beta particles are filtered out so that only the Y^{90} betas actually reach the lesion. The lens is not irradiated.[1]

"Radiation curettage," destruction of the uterine mucosa by radiation from a Sr^{90} source placed in the uterine cavity, has been recommended for control of endometrial bleeding when no malignancy is indicated.[79]

Sr^{85} (65 d, no β, 0.5-Mev γ). Strontium-85 has been used for localizing bone tumors[80] and for studying bone metabolism. Because of its shorter half-life, irradiation of the body is less than with Sr^{90}. Its gamma radiation can be detected externally.

Sr^{87m} (2.8 hr, 0.39-Mev γ). This isotope, which can be obtained quickly, as needed, from 80-hr Y^{87}, has been mentioned[81] for possible use in obtaining information available in a short time; for example, circulation time, cardiac output, and various clearances, and in radiography.

Y^{90} (64.5 hr, 2.27-Mev β). Injected ceramic Y^{90} particles of ~60 μ dia., which are trapped in capillaries of the lung, liver, and other organs, have been used for cancer therapy.[82] Thirty-five patients with Parkinson's disease were improved by brain implants of ceramic Y^{90} beads.[83] Carrier-free Y^{90} may be eluted[84] with citrate from a cation exchange resin preparation of Sr^{90}. It may be infiltrated as a solution, implanted in a plastic filament, or applied in a bag or absorbed in blotting paper.[85]

Because it is a pure beta emitter, colloidal Y^{90} results in less exposure of hospital personnel than Au^{198}, and it has been used for control of malignancy-induced effusions.[86] Complete pituitary destruction has been reported as a result of packing the fossa, following surgery, with powdered Y^{90} dispersed in wax.[87] For superficial radiation therapy, Y^{90} has been incorporated in small plates, which can be selected to cover an irregular area.[88] Transperineal injection of Y^{90} has been used for prostatic cancer.[89] Intravenous Y^{90} gave good results in eight polycythemia vera patients.[90]

Calcium

Ca^{45} (164 d, 0.25-Mev β, no γ). Calcium-45 has been used for studying calcium metabolism, Paget's disease of bone, and hypoparathyroidism.[91]

Ca^{47} (4.7 d, 0.66-and 1.94-Mev β's, 0.48- to 1.3-Mev γ's; accompanied by 3.5 d Sc^{47} daughter with 0.46- and 0.62-Mev β's and 0.175-Mev γ). Possible medical uses of the now-available Ca^{47}, which is of interest because of its high gamma energy, are being extensively investigated.[92]

Cobalt

Co^{60} (5.3 y, 0.31-Mev β, 1.17- and 1.33-Mev γ). By far the largest use of Co^{60} is in teletherapy units,[1b,c,93] descriptions of which may be obtained from various equipment manufacturers (see also book review section of this issue). Such units were widely distributed by 1959 (Table VI-2).[94] In 1962 they were reported to number 1400, of which 550 are in the U.S.A. and Latin America.[95] They are reported[96]

Footnotes to Table VI-2.

[a]Reprinted, with minor style changes, from reference 94.

[b]These figures represent the number of licenses issued as of August 1, 1959; they do not include such teletherapy installations as those at Oak Ridge Institute of Nuclear Studies and Argonne Cancer Research Hospital, for which no license was required.

[c]Estimated, mainly low curie units.

[d]Including only countries for which information is available.

Table VI-2. Radioisotope Teletherapy Source Distribution

Location	Unit Ir^{192}	Unit Cs^{137}	Unit Co^{60}
Africa			
Algeria	-	-	1
Union of South Africa	-	-	1
America			
Argentina	-	-	3
Brazil	-	-	8
Canada	-	2	24
Chile	-	-	2
Cuba	-	-	2
El Salvador	-	-	1
Mexico	-	-	12
Peru	-	-	1
Puerto Rico	-	-	2
United States	-	6[b]	264[b]
Uruguay	-	-	2
Venezuela	-	-	5
Asia			
Burma	-	-	1
Ceylon	-	-	1
China (Taiwan)	-	-	1
Hong Kong	-	-	1
India	-	-	3
Indonesia	-	-	1
Iran	-	-	1
Israel	-	-	3
Japan	-	-	200[c]
Lebanon	-	-	1
Philippines	-	-	4
Thailand	-	-	1
Europe			
Austria	-	-	2
Belgium	-	-	2
Denmark	-	-	2
Finland	-	-	1
France	-	1	40
Germany (Fed. Republic)	-	-	4
Greece	-	-	3
Hungary	-	-	1
Italy	-	-	26
Monaco	-	-	1
Netherlands	-	-	4
Norway	-	1	-
Portugal	-	-	1
Spain	-	-	5
Sweden	-	-	7
Switzerland	-	-	4
United Kingdom	1	8	33
Yugoslavia	-	-	1
Oceania			
Australia	-	-	4
New Zealand	-	-	2
Total[d]	1	18	689

See following page for footnotes.

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to be in use in Communist China, and have been referred to as the most important product of Atomic Energy of Canada Ltd.[97] A nonroutine use of Co^{60} teletherapy is a possible new treatment for leukemia in which blood, circulated outside the body through a tube, is exposed to Co^{60} radiation.[98]

Cobalt-60 needles have been implanted in tumors, and seeds enclosed in nylon tubing have been used in interstitial therapy and in wounds after surgery for a malignant condition.[99] Spheres of Co^{60}, gold-plated to prevent dusting, may be placed in hollow organs such as the uterus or bladder.[100] Cobalt-60 may be incorporated in plastic and molded to fit irregular areas such as the oral cavity.[101]

Vitamin B_{12} labeled with Co^{60} has been used in diagnosing pernicious anemia[102] and localizing liver tumors.[103]

Other Cobalt Isotopes. Co^{56} (77.3 d, 0.44- and 1.46-Mev β, 0.85-1.75-Mev γ); Co^{57} (270 d, no β, 0.014- and 0.12-Mev γ); Co^{58} (71 d, 0.48-Mev β, 0.81-Mev γ). Various other cobalt isotopes have been used[1] to label vitamin B_{12}. Cobalt-57 is reported[104] to give the lowest irradiation of a patient. Labeled vitamin B_{12} (Co^{57}) has been shown to concentrate in the parathyroid in dogs[105] and is therefore potentially useful in parathyroid conditions.

Cesium

Cs^{137} (30 y, 0.51- and 1.18-Mev β, 0.662-Mev γ from daughter Ba^{137}). This isotope, which is recovered as a by-product from the processing of nuclear reactor fuel, is a relatively new isotope, but many Cs^{137} teletherapy units are in use (Table VII-2). The long half-life and low cost of the activity are the principal advantages over Co^{60}. Typical units have been described elsewhere.[1c,93a,106] (See also book review section of this issue.)

Iridium

Ir^{192} (74 d, 0.67-Mev β, 0.30- to 0.47-Mev γ's). Radioiridium teletherapy is an old idea.[107] A new 100-curie Ir^{192} irradiation unit weighs only 38 lb; a 10-curie source weighing 28 lb is also available.[108] A unit with interchangeable ends of different sizes and shapes, for interorificial therapy, has been described recently.[109]

The half-life of Ir^{192} is about 5% that of Co^{60}, and its less penetrating gamma rays allow greater local absorption and necessitate less protection for hospital personnel. Internally, it has been used as seeds embedded in nylon ribbon or as needles.[110] Experimentally, an Ir^{192}-labeled resin suspension has been used with external counting for determining gastric emptying rates.[111]

Arsenic and Copper

As^{74} and Cu^{64} (17.4 d and 12.8 hr, respectively; positron emitters). These isotopes have been used for localizing brain tumors.[112]

As^{76} (26.5 hr) and As^{72} (26 hr). Arsenic-76 has been used for brain tumor localization, as has As^{72}, which yields nearly three times as many positrons per average disintegration[113] as As^{74}.

Gallium

Ga^{72} (14.3 hr, 0.64- and 0.96-Mev β's, 0.63- to 2.20-Mev γ's). Gallium-72 has been used to localize malignant bone tumors by external measurements, but the short half-life results in a concentration of this chemically toxic material which may perhaps be higher than is warranted by the radiation delivered.[114]

Ga^{68} (68 min, 1.9-Mev β, 1.1-Mev γ). Gallium-68 has been suggested for such applications as brain tumor localization by annihiscopy. A source from which Ga^{68} can be easily and rapidly obtained has been designed.[115]

Palladium

Pd^{109} (13.5 hr, 1.03-Mev β) and Pd^{103} (17 d). A mixture of these two isotopes has been used for interstitial irradiation.[116]

Tantalum

Ta^{182} (115 d, 0.36- to 0.51-Mev β's, 1.12- and 1.22 Mev γ's). Tantalum-182 wires have been used as tissue implants in control of malignant conditions.[117]

Ruthenium-Rhodium

Intragastric beta irradiation with Ru^{106}-Rh^{106} has been tried.[118]

Lutetium

Lu^{177} (175 d; also 6.8 d, 0.50-Mev β, 0.18- and 0.38-Mev γ). Lutetium-177 has been suggested for infiltration to lymph nodes involved in malignant disease.[119]

Sulfur

S^{35} (87 d, 0.167-Mev β, no γ). Sulfur-35 has been used for determining extracellular water and as a therapeutic agent in chondrosarcoma and mycosis fungoides.[120] Labeling of Congo red dye with S^{35} decreases the amount of dye needed for diagnosis of amyloidosis, eliminating the side effects that occur in some patients.[121] Methionine labeled with S^{35} has been suggested for use in detecting pancreas tumors.[122]

Sodium

Na^{22} (2.6 y, 0.54-Mev β, 1.3-Mev γ) and Na^{24} (15 hr, 1.4-Mev β, 2.7- and 1.4-Mev γ's). These isotopes have been used for measuring extracellular water, sodium space, and exchangeable sodium; for determining when skin grafts are complete; and for cancer therapy.[1,123] Because of its shorter half-life, Na^{24} has advantages for some uses.

Potassium

K^{42} (12.4 hr, 3.6-Mev β, 1.5-Mev γ) and K^{43} (22 hr, 0.3- and 0.27-Mev β's, 0.37- to 0.62-Mev γ's). These isotopes have been used to localize brain and breast tumors, measure exchangeable potassium, and study potassium uptake by red blood cells.[1,124] Less shielding is re-

[redacted]

Rubidium

Rb^{86} (19 d, 1.78- and 0.72-Mev β's, 1.1-Mev γ). Since rubidium acts similarly to potassium and has a more convenient half-life than K^{42}, it has been suggested for use in determining exchangeable potassium.[124c] However, it must be remembered that Rb^{86} is not a potassium isotope. Myocardial scanning tests have been made with Rb^{86} in dogs.[125]

Bromine and Chlorine

Br^{82} (35.7 hr, 0.44-Mev β, 0.55- to 0.78-Mev γ's). Bromine-82 ratios in blood and spinal fluid have been used to differentiate between tuberculous and nontuberculous meningitis.[126] For determining

Ag^{111} was one of the early radioactive colloids used.[128] Silver-111, injected into the bloodstream as a protein-silver complex, is removed less rapidly by a cirrhotic liver than by a normal one.[129]

Zinc

Zn^{63} (38 min, 1.38- to 2.34-Mev β's, 0.67- and 0.96-Mev γ's). Zinc-63 was used in early work for control of malignant effusions.[1] Its use in studying zinc metabolism was reported recently.[130]

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Radiology, 35: 51-9 (1940) (7 patients, treatment started in 1939).

3. E.g., Conf. on Use of Radioisotopes in Medicine, Hamburg, 1954 (Strahlentherapie, 97: 621-32 (1955)); All-Union Conf. on Medical Radiology, Moscow, 1956; All-Union Conf. on the Application of Radioactive and Stable Isotopes in the National Economy and Science, biological and medical papers, Moscow, 1957; Medical Radioisotope Scanning, Vienna, 1959 and New York, 1962 [Nucleonics, 20(5): 96 (May 1962)]; Radioisotopes in Tropical Medicine, Bangkok, 1960; Whole-body Counting, Vienna, 1961; Uses of Radioisotopes in Animal Biology and the Medical Sciences, Mexico City, 1961; Peaceful Uses of Atomic Energy, Geneva, medical and biological papers, 1955 and 1958; Japan conferences on radioisotopes, medical and biological papers, No. 4 in 1961; uses of radioisotopes including clinical, Rumania (Priroda, October 1962, p. 112); Luchevaya Terapiya pri Neopukholevykh Zabolevaniyakh (Simpozium), Med. Radiol., 7(9): 3-85 (September 1962).

4. E.g., Journal of Nuclear Medicine; Radiology; The American Journal of Roentgenology; Radium Therapy and Nuclear Medicine; The British Journal of Radiology; La Radiologia Medica; Journal Belge de Radiologie; Minerva Nucleare; Radiologia Austriaca; Strahlentherapie; Meditsinskaya Radiologiya; Nuclear Medizin; The International Journal of Applied Radiation and Isotopes.

5. E.g., International Atomic Energy Agency, Nuclear Medicine: A Guide to Recent Literature, Lists 1, 2, 3, and 4 (list 4 issued February 1963).

6. E.g., (a) K. E. Halnan, Atomic Energy in Medicine, The Atoms for Peace Series, Philosophical Library, New York, 1957.

(b) Nuclear-Chicago Corporation, Diagnostic Applications of Radioactive Isotopes (documented booklet of procedures), 1960.

(c) The Year Book of Radiology, Year Book Medical Publishers, Chicago (annual).

(d) T. Nagai, Radioisotopic diagnosis in internal medicine, Jap. J. Internal Med., 10: 606-20 (1962). (in Japanese).

7. G. A. Andrews, Medical students and radioisotopes, The New Physician, 9(12): 23-7 (1960).

8. (a) E.g., J. Nucl. Med., 1: 239-50 (1960); 3: 487-96 (1962).

(b) G. V. LeRoy, AEC licensing of radioisotopes for clinical research, Atomlight, No. 26, p. 1 (February 1963), New England Nuclear Corp. (AEC policies are given in Federal Register, Title 10 Code of Federal Regulations, Part 30).

9. J. H. Lawrence, Isotopes and nuclear radiations in medicine: A quarter century of nuclear medicine, Proc. Conf. Use Radioisotopes Animal Biol. Med. Sci., Mexico City, 1: 1-22 (1961), IAEA, Vienna.

10. Minn. Mining & Mfg. Co., 3M Brand Radiating Microspheres, St. Paul, Minnesota.

11. G. T. Seaborg, The role of research in our atomic energy program, Ann. Mtg. Soc. Nucl. Med., Dallas, June 1962.

12. M. H. Cross, L. H. Shuman, Placentography (abs.), J. Nucl. Med., 3: 215-6 (1962).

13. N. O. Whitley, R. L. Witcofski, J. E. Whitley, A radioisotopic approach to the estimation of mitral valve size, J. Nucl. Med., 3: 305-8 (1962).

14. (a) M. M. Magalotti, I. F. Hummon, Localization of intracranial lesions by radioactive isotopes (D. I. F.) (RISA), Am. J. Roentgenol. Radium Therapy Nucl. Med., 83: 135-44 (1960).

(b) J. Th. van der Werff, Gamma encephalographie, J. Belge Radiol., 44: 431-4 (1961).

(c) K. Amplatz, J. Marvin, P. W. Winchell, G. Gomez, P. Adams, R. G. Lester, A simple isotope dilution technique for quantitative determination of left-to-right shunts, Am. J. Roentgenol. Radium Therapy Nucl. Med., 85: 1053-8 (1961).

(d) M. H. Wholey, J. H. Walker, J. M. Hartman, J. Haskins, The application of radioactive gas in the detection and quantification of left-to-right cardiac shunts, Radiology, 79: 51-63 (1962).

(e) F. F. McMullen, W. C. Sutton, H. C. Allen, H. H. Hanson, Detection of the small left-to-right intracardiac shunt with methyl iodide I^{131}, J. Nucl. Med., 3: 367-81 (1962).

15. G. V. Taplin, J. Hayashi, D. E. Johnson, E. Dore, Liver blood flow and cellular function in hepatobiliary disease. Tracer studies with radiogold and Rose Bengal, J. Nucl. Med., 2: 204-17 (1962).

16. A. Ozarda, J. Pickren, The topographic distribution of liver metastases. Its relation to surgical and isotope diagnosis, J. Nucl. Med., 3: 149-52 (1962).

17. (a) F. Feldman, S. Rubenfeld, C. Collica, The radioactive (I^{131}) Rose Bengal hepatoscan, Radiology, 79: 457-70 (1962).

(b) H. Ghadimi, A. Sass-Kortsak, Evaluation of the radioactive Rose Bengal test for the differential diagnosis of obstructive jaundice in infants, New Eng. J. Med., 265: 351-8 (1961).

18. (a) D. E. Johnson, G. V. Taplin, E. K. Dore, J. Hayashi, The radioisotope renocystogram, J. Nucl. Med., 2: 8-23 (1961).

(b) R. A. Nordyke, R. G. Rigler, W. S. Strode, Radioisotope renography, Am. J. Roentgenol. Radium Therapy Nucl. Med., 88: 311-5 (1962).

(c) P. Tothill, A. Doig, J. R. Lawrence, The use of I^{131}-labeled Hippuran for renal function studies (abs.), Brit. J. Radiol., 35: 363 (1962).

19. W. H. Oldendorf, Measurement of the mean transit time of cerebral circulation by external detection of an intravenously injected radioisotope, J. Nucl. Med., 3: 382-98 (1962).

20. J. I. Fabrikant, W. G. Anlyan, G. J. Baylin, J. K. Isley, Isotope studies for the evaluation of venous disease of the lower extremity, J. Nucl. Med., 3: 136-48 (1962).

21. M. Tubis, R. A. Nordyke, E. Posnick, W. H. Blahd, The preparation and use of I^{131}-labeled sulfobromophthalein in liver function testing, J. Nucl. Med., 2: 282-8 (1961).

22. D. Berkowitz, W. Likoff, J. J. Spitzer, D. M. Sklaroff, The use of radioactive fat in the study of fat metabolism, J. Nucl. Med., 1: 31-40 (1960).

23. F. J. Bonte, G. J. Andrews, E. A. Elmendorf, N. L. Presley, J. S. Krohmer, Radioisotope scanning in the detection of pericardial effusions, Southern Med. J., 55: 577-80 (1962).

24. (a) R. C. Meade, H. M. Klitgaard, A simplified method for immunoassay of human serum insulin, J. Nucl. Med., 3: 407-16 (1962).

(b) J. L. Izzo, W. F. Bale, M. J. Izzo, A. Roncone, High-specific-activity labelling of insulin with I^{131} (abs.), Federation Proc., 21(2): 204 (March-April 1962).

25. W. Horst, A. Jores, C. Schneider, Strahlenbehandlung euthyreoter Strumen mit Radiojod J^{131}, Deut. Med. Wchschr., 85: 723-9, 733-4 (1960).

26. S. Chiappa, S. Galli, S. Barbaini, G. Ravasi, La radiotherapia endolinfatica: primi risultati di una nuova metodica, La Radiol Med., 48: 663-92 (1962).

27. (a) H. L. Blumgart, A. S. Freedberg, G. S. Kurland, Treatment of incapacitated euthyroid cardiac patients with radioactive iodine: summary of results in treatment of 1070 patients with angina pectoris or congestive failure, J. Am. Med. Assoc., 157: 1-4 (1955).
(b) W. Horst, E. Gadermann, Ergebnisse der Strahlenresektion bzw. Elimination der Schilddrüse mit Radiojod bei fortgeschrittenen Herzerkrankungen, Strahlentherapie, 97: 87-93 (1955).

28. F. Comas, M. Brucer, Irradiation of the ovaries from the urinary excretion of I^{131}, Am. J. Roentgenol. Radium Therapy Nucl. Med., 83: 501-6 (1960).

29. W. G. Myers, J. C. Vanderleeden, Radioiodine-125, J. Nucl. Med., 1: 149-64 (1960).

30. (a) H. Endlich, P. Harper, R. Beck, W. Siemens, K. Lathrop, The use of I^{125} to increase isotope scanning resolution, Am. J. Roentgenol. Radium Therapy Nucl. Med., 87: 148-55 (1962).
(b) W. G. Myers, P. M. Dettman, Radioiodine-125 for clinical photon projection analysis, J. Nucl. Med., 2: 138 (1961).

(c) P. M. Dettman, W. G. Myers, Radioiodine-125 for evaluation of thyroid function, Surg. Forum, 12: [illegible] (196[illegible]).

31. (a) C. C. Winter, W. G. Myers, Three new test agents for the radioisotope renogram: DISA-I^{131}, EDTA-Cr^{51}, and Hippuran-I^{125}, J. Nucl. Med., 3: 273-81 (1962).

(b) C. C. Winter, W. G. Myers, Clinical use of I^{125} in kidney function testing, Ohio State Univ. Health Center J., 12(3): viii (Spring 1962).

(c) C. C. Winter, W. G. Myers, I^{125}, a new radioisotope for the labelled Hippuran renogram, J. Urol., 88: 100-2 (1962).

32. L. M. Levy, T. T. Estrellado, O. O'Kezie, H. S. Stern, The use of I^{125} in clinical nuclear medicine (abs.), J. Nucl. Med., 3: 183 (1962).

33. Item in Denver Post, Dec. 9, 1962, p. 5AAA (reported in Technical Survey, 18: 889 (1962).)

34. M. H. Croll, D. Berkowitz, Simultaneous absorption studies of I^{131}-triolein and I^{125}-oleic acid in the differential diagnosis of steatorrhea (abs.), J. Nucl. Med., 3: 213 (1962).

35. W. G. Myers, On a new source of x rays, Ohio State Med. J., 58: 772-3 (1962).

36. I. J. Gruverman, J. K. Schivley, I^{125} makes a better low-energy gamma radiography source, Nucleonics, 21(5): 96-7 (May 1963).

37. (a) C. M. Neil, Preliminary evaluation of the I^{132} solution from the Brookhaven Te^{132}-I^{132} generator, J. Nucl. Med., 3: 352-9 (1962).

(b) U. Feine, Über die Methode der Jod-132 Abtrennung in Aluminumoxydsäulen und ihre Eignung für die medizinische Radiojoddiagnostik, Nucl. Med., 1: 159-66 (1961).

(c) K. E. Halnan, E. E. Pochin, The use of I^{132} for thyroid function tests, Brit. J. Radiol., 31: 581-8 (1958).

(d) G. B. Cook, J. Eakins, N. Veal, The production and clinical applications of I^{132}, Intern. J. Appl. Radiation Isotopes, 1: 85-93 (1956).

38. R. C. Cavalieri, E. R. King, The use of I^{132} to study thyroid function following therapy with I^{131}, J. Nucl. Med., 3: 436-44 (1962).

39. W. G. Myers, H. O. Anger, Radioiodine-123 (abs.), J. Nucl. Med., 3: 183 (1962).

40. (a) C. M. E. Matthews, B. A. Tucker, Theoretical comparison of I^{124} and I^{131} thyroid dosimetry, Phys. Med. Biol., 5: 245-53 (Jan. 1961).

(b) N. A. Dyson, P. E. Francois, Some observations on the decay of I^{124} and their implications in radioiodine therapy, Phys. Med. Biol., 3: 111-22 (1958).

(c) M. Berman, J. E. Ball, J. Heslin, Some physical considerations governing the choice of internally administered radioisotopes for therapy, Phys. Med. Biol, 1: 243-57 (1957).

41. J. R. Maxfield, Jr., J. G. S. Maxfield, W. S. Maxfield, The use of radioactive P and testosterone in metastatic bone lesions from breast and prostate, Southern Med. J., 51: 320-8 (1958).

42. R. Y. Card, D. R. Cole, U. K. Henschke, Summary of 10 years of the use of radioactive colloids in intracavitary therapy, J. Nucl. Med., 1: 195-203 (1960).

43. (a) C. Rusche, H. L. Jaffe, Palliative treatment of prostatic cancer with radioactive colloidal chromic phosphate, J. Urol., 74: 393-401 (1955).

(b) J. M. Hill, E. Loeb, R. J. Speer, Intravenous colloidal zirconyl phosphate-P^{32}. Clinical studies in over 250 cases (abs.), J. Nucl. Med., 3: 196 (1962).

44. P. Czerniak, P^{32} studies of spermatogenesis in man; establishment of a spermatogenic activity test, Am. J. Roentgenol. Radium Therapy Nucl. Med., 88: 327-35 (1962).

45. B. Goldberg, D. Tabowitz, G. B. Kara, S. Zavell, R. Espiritu, The radioactive phosphorus test in ophthalmology (abs.), J. Nucl. Med., 3: 228 (1962).

46. H. L. Atkins, mentioned in "Scanning: A guide to therapy," Nucleonics, 20(10): 102 (October 1962).

47. (a) R. Adams, A. Y. Hindawi, Kh. Qassab, Localization of hydatid liver cysts with colloidal radiogold, J. Nucl. Med., 3: 315-22 (1962).

(b) P. Czerniak, E. Lubin, M. Djaldetti, A. DeVries, Scintillographic follow-up of amoebic abscess and hydatid cysts of the liver, J. Nucl. Med., 4: 35-44 (1963).

48. (a) R. H. Flocks, D. A. Culp, H. B. Elkins, Present status of radioactive gold therapy in management of prostatic cancer, J. Urol., 81: 178-84 (1960).

(b) R. J. Dickson, E. K. Lang, Treatment of papillomata of the bladder with radioactive colloidal gold (Au^{198}), Am. J. Roentgenol. Radium Therapy Nucl. Med., 83: 116-22 (1960).

(c) R. J. Dickson, Three years experience in the therapeutic use of radioactive gold grains, J. Nucl. Med., 1: 204-11 (1960).

(d) A. Verhagen, G. Muszynski, Unsere Erfahrungen mit der interstitiellen Radiogoldtherapie beim Kollumkarzinom, Strahlentherapie, 116: 97-130 (1961).

49. P. F. Hahn, G. R. Meneely, R. I. Carlson, W. Alsobrook, Adjuvant use of Ag-coated radioactive colloidal Au in treatment of bronchogenic carcinoma by pneumonectomy, J. Nucl. Med., 1: 273-9 (1960).

50. G. H. Jantet, Direct intralymphatic injections of radioactive colloidal gold in the treatment of malignant disease, Brit. J. Radiol., 35: 692-7 (1962).

51. P. F. Hahn, D. G. Laureau, B. L. Feaster, E. L. Carothers, F. Gollan, G. R. Meneely, D. Sherman, Intravenous radioactive gold in the treatment of chronic leukemia, Acta Radiol., 50: 565-72 (1958).

52. (a) R. G. Rose, Intracavitary radioactive colloidal gold: Results in 257 cancer patients, J. Nucl. Med., 3: 323-31 (1962).

(b) P. B. Hansen, A. Haug, Treatment of pleural and peritoneal carcinomatous effusions with radioactive gold (1956-59), Acta Radiol., 53: 321-8 (1960).

(c) A.M.A. Council on Pharmacy and Chemistry, New and nonofficial remedies. Radiogold (Au^{198}) colloid, J. Am. Med. Assoc., 159: 1294-5 (1955).

(d) K. P. Bachman, C. G. Foster, M. A. Jackson, P. H. Shershim, H. C. Oard, Radioactive gold instilled intrapericardially. Report of a case, Ann. Internal Med., 40: 811-9 (1954).

53. G. B. Udvarhelyi, Radiation hypophysectomy with Au^{198}, Southern Med. J., 55: 377-84 (1962).

54. (a) F. Heinzel, Klinische Erfahrungen mit der Hypophysektomie,

Fortschr. Gebiete Roentgenstrahlen Nuklearmed., 95: 313-23 (1961).

(b) K. E. Scheer, E. Klar, Pituitary implantation with Au^{198}. A report of 500 cases, Nucl. Med., 2: 143-51 (1961).

55. (a) J. A. Williams, J. Fine, Measurement of blood volume with a new apparatus, New Eng. J. Med., 264: 842-8 (1961).

(b) J. A. Williams, J. B. Williams, Clinical nuclear instrument measures blood volume, Nucleonics, 20(11): 63-4 (November 1962).

56. W. N. Tauxe, Quantitation of menstrual blood loss: A radioactive method utilizing a counting dome, J. Nucl. Med., 3: 282-7 (1962).

57. H. N. Wagner, Jr., J. G. McAfee, Diagnosis of splenic disease by radioisotope scanning (abs.), J. Nucl. Med., 3: 201 (1962).

58. T. A. Waldmann, Gastrointestinal protein loss demonstrated by Cr^{51}-labelled albumin, Lancet, 1961-II: 121-3.

59. (a) W. G. Myers, Neutron-radioactivated pure chromium crystals as sources of γ rays from radiation chemotherapy, Radiology, 66: 268 (1956).

(b) W. G. Myers, Radioactive Cr^{51} γ ray sources, Am. J. Roentgenol. Radium Therapy Nucl. Med., 81: 99-106 (1959).

60. Abbott Laboratories, Fe^{59}: Radioiron Preparations, Abbott Labs., North Chicago, Ill., and Oak Ridge, Tenn. (documented pamphlet).

61. M. A. Escobar, A. Emanueli, F. E. Trobaugh, A method for studying Fe absorption using $ferrous^{59}$ sulfate tablets (abs.), J. Nucl. Med., 3: 227 (1962).

62. F. Stohlman, Jr., The use of Fe^{59} and Cr^{51} for estimating red cell production and destruction: An interpretative review, Blood, 18: 236-50 (1961).

63. (a) T. H. Bothwell, H. van W. van Doorn-Wittkampf, M. L. DuPreez, T. Alper, The absorption of iron. Radioiron studies in idiopathic hemochromatosis, malnutritional cystosiderosis and transfusional hemosiderosis, J. Lab. Clin. Med., 41: 836-48 (1953).

(b) R. Van Hoek, M. E. Conrad, Jr., Iron absorption. Measurement of ingested Fe^{59} by a human whole-body liquid scintillation counter, J. Clin. Investig., 40: 1153-9 (1961).

64. (a) C. T. Ray, G. E. Burch, S. A. Threefoot, F. J. Kelly, The distribution of radiomercury in some of the body fluids of man, Am. J. Med. Sci., 220: 160-5 (1950).

(b) F. J. Kelly, A. H. Svedberg, V. C. Harp, Jr., The transfer of radioactive Hg across a membrane produced by the application of cantharides to the skin of man, J. Clin. Invest., 29: 988-97 (1950)

(c) S. A. Threefoot, C. T. Ray, G. E. Burch, J. A. Cronvich, J. P. Milnor, W. Overman, W. Gordon, Concentration-time course in the plasma of man of radiomercury introduced as a mercurial diuretic, J. Clin. Invest., 28: 661-70 (1949).

65. (a) M. Blau, M. A. Bender, Radiomercury (Hg^{203}) labeled Neohydrin: A new agent for brain tumor localization, J. Nucl. Med., 3: 83-93 (1962).

(b) R. L. Bell, G. J. Hertsch, The determination of cerebral circulation time, J. Nucl. Med., 3: 399-406 (1962).

66. (a) T. P. Haynie, B. H. Stewart, M. M. Nofal, E. A. Carr, Jr., W. H. Beierwaltes, Renal scintiscans in the diagnosis of renal vascular disease, J. Nucl. Med., 2: 272-81 (1961).

(b) J. G. McAfee, H. N. Wagner, Visualization of renal parenchyma by scintiscanning with Hg^{203} Neohydrin, Radiology, 75: 820-1 (1960).

(c) R. C. Reba, H. N. Wagner, Jr., J. G. McAfee, Measurement of Hg^{203} Chlormerodrin accumulation by the kidneys for detection of unilateral renal disease, Radiology, 79: 134-5 (1962).

67. L. E. Farr, L. Y. Yamamoto, Neutron capture therapy of a cerebellar hemangiosarcoma after surgical and radiation treatment, J. Nucl. Med., 2: 253-71 (1961).

68. L. E. Farr, T. Konikowski, Absolute control of an experimental sarcoma in mice by boron thermal neutron interaction (abs.), Federation Proc., 21(2): 422 (1962).

69. A. B. Eschenbrenner, mentioned in ORINS Newsletter, December 1962, p. 2.

70. M. Blau, W. Nagler, M. A. Bender, F^{18}: A new isotope for bone scanning (prelim. progress note), J. Nucl. Med., 3: 332-4 (1962).

71. M. Anbar, M. Inbar, The application of F^{18} labelled fluoroborate ions to problems in thyroid physiology, Israel Atomic Energy Com. report IA-754, July 1962 (9 pp.)

72. H. M. Askenasy, M. Anbar, Y. Laor, Z. Lewitus, I. Z. Kosary, S. Guttermann, The localization of intracranial space-occupying lesions by fluoroborate ions labelled with F^{18}, Am. J. Roentgenol. Radium Therapy Nucl. Med., 88: 350-4 (1962).

73. (a) M. Blau, R. F. Manske, The pancreas specificity of Se^{75}-selenomethionine, J. Nucl. Med., 2: 102-5 (1961).

(b) M. Blau, M. A. Bender, Se^{75}-selenomethionine for visualization of the pancreas by isotope scanning (prelim. rept.), Radiology, 78: 974 (1962).

74. R. J. Sanders, The uses of Kr^{85}, J. Nucl. Med., 3: 230-1 (1962).

75. E. Braunwald, R. T. Long, A. G. Morrow, Injections of radioactive krypton (Kr^{85}) solutions in the detection and localization of cardiac shunts (abs.), J. Clin. Invest., 38: 990 (1959).

76. (a) R. J. Sanders, A. G. Morrow, The identification and quantification of left-to-right circulatory shunts, Am. J. Med., 26: 508-16 (1959).

(b) R. J. Sanders, A. G. Morrow, The localization of circulatory shunts with inhaled Kr^{85} (prelim. clinical rept.), Bull. Johns Hopkins Hosp., 103: 27-31 (1958).

77. H. H. Byun, G. Albrecht, G. W. Holmes, R. S. Lanauer, Pulmonary function studies using Kr^{85} (abs.), J. Nucl. Med., 3: 191 (1962).

78. J. A. Herd, M. Hollenberg, G. D. Thorburn, H. H. Kopald, A. C. Barger, Myocardial blood flow in the unanesthesized dog using Kr^{85} (abs.), Federation Proc., 21(2): 105 (March-April 1962).

79. P. Czerniak, E. Rabau, K. Rikower, Sr^{90} in the treatment of cystic glandular hyperplasia of the endometrium, Proc. U. N. Intern. Conf. Peaceful Uses At. Energy, 2nd, Geneva, 26: 381-6 (1958).

80. D. M. Sklaroff, Studies of metastatic bone lesions with Sr^{85} (abs.), J. Nucl. Med., 3: 208 (1962).

81. W. G. Myers, Radiostrontium-87m , J. Nucl. Med., 1: 125 (1960).

82. (a) E. D. Grady, W. Sale, L. C. Rollins, Large-particle Y^{90} intravenously to treat lung cancer (abs.), J. Nucl. Med., 3: 336-7 (1962).

(b) E. D. Grady, W. Sale, L. C. Rollins, Large particles of Y^{90} to treat advanced cancer (abs.), J. Nucl. Med., 3: 229 (1962).

(c) I. M. Ariel, Organ irradiation by means of radiating microspheres (abs.), J. Nucl. Med., 3: 195 (1962).

(d) I. M. Ariel, Interstitial use of radiating microspheres (abs.), J. Nucl. Med., 3: 335-6 (1962).

83. P. Crandall, J. C. Westover, mentioned in Sci. News Letter, 81: 388 (1962).

84. R. F. Doering, W. D. Tucker, L. G. Stang, Jr., A simple device for safely milking carrier-free Y^{90} from Sr^{90}, J. Nucl. Med., 4: 54-9 (1963).

85. J. Greenberg, H. C. Dudley, Radioactive yttrium (Y^{90}) in interstitial therapy (abs.), J. Nucl. Med., 3: 193 (1962).

86. E. P. Siegel, H. E. Hart, M. Brothers, H. Spencer, D. Laszlo, Radioyttrium (Y^{90}) for the palliative treatment of effusions due to malignancy, J. Am. Med. Assoc., 161: 499-503 (1956).

87. (a) G. A. Edelstyn, C. A. Gleadhill, A. R. Lyons, H. W. Rodgers, A. R. Taylor, R. B. Wilbourn, Hypophysectomy combined with intra-sellar irradiation with Y^{90}, Lancet, 1958-I: 462-3.

(b) A. P. M. Forrest, D. W. Blair, J. M. Valentine, Screw-implantation of the pituitary with Y^{90}, Lancet, 1958-II: 192-3.

88. (a) J. Becker, K. E. Scheer, Das β-Mosaik: Eine anpassungsfähige Strahlenquelle für die Oberflächentherapie, Strahlentherapie, 107: 112-6 (1958).

(b) G. Baroncelli, L. Mango, G. Tunesi, La posizione dello Sr^{90} nella radioterapia di contatto, La Radiol. Med., 48: 635-62 (1962).

(c) E. P. Malaise, M. Lapière, P. Labeye, M. J. Guillaume, Note technique: Traitement des angiomes plans chez des enfants en bas age par des plaques imbibées d'Y^{90}, J. Belge Radiol., 44: 277-87 (1961).

89. G. J. Bulkley, J. A. D. Cooper, V. J. O'Connor, Present status of treatment of the prostate with radioactive materials, J. Urol., 75: 837-45 (1956).

90. J. Greenberg, A. Sawitsky, H. C. Dudley, R. N. Levy, K. R. Rai, Therapy of polycythemia vera with radioyttrium (Y^{90}), J. Nucl. Med., 3: 18-25 (1962).

91. S. M. Krane, G. L. Brownell, J. B. Stanbury, H. Corrigan, The effect of thyroid disease on calcium metabolism in man, J. Clin. Invest., 35: 874-7 (1956).

92. (a) R. P. Heaney, G. D. Whedon, Radiocalcium studies of bone formation rate in human metabolic bone disease, J. Clin. Endocrinol. Metab., 18: 1246-67 (1958).

(b) International Atomic Energy Agency, Medical Uses of Ca^{47}, Report of a Conference 6-8 December, 1961, Technical Report Series No. 10, IAEA, Vienna, 1962.

93. (a) M. Brucer, Teletherapy devices with radioactive isotopes, Proc. Intern. Conf. Peaceful Uses At. Energy Geneva, 10: 68-74 (1955).

(b) L. H. Lanzl, L. S. Skaggs, Kilocurie revolving Co^{60} therapy unit, Proc. Intern. Conf. Peaceful Uses At. Energy, Geneva, 10: 75-80 (1955).

(c) C. B. Braestrup, R. T. Mooney, Co^{60} teletherapy isodose patterns for combined and nonuniform longitudinal and transverse source motions, Proc. Intern. Conf. Peaceful Uses At. Energy, Geneva, 10: 81-8 (1955).

(d) M. Brucer, H. D. Kerman, J. E. Richardson, Teletherapy Design Problems: Co^{60} Teletherapy Unit, USAEC Report ORO-109 (1953).

(e) M. Brucer, H. Harmon, Teletherapy Design Problems III, USAEC Report ORO-127 (1954).

94. International Atomic Energy Agency and World Health Organization, Use of Radioisotopes and Supervoltage Radiation in Radioteletherapy: Present Status and Recommendations, IAEA, Vienna, 1960.

95. Isotopes get hot, Chem. Week, 91(51): 54-7 (Dec. 22, 1962).

96. Clinical radiology in Communist China, Nucleonics, 20(11): 70 (October 1962) (from Chinese J. Radiol. translation).

97. Nuclear power development in Canada, Atomics, 16(1): 6-18 (January-February 1963).

98. Item in New Scientist, 13: 424 (1962).

99. (a) G. G. Binnie, N. Bates, Curved Co needles in radiotherapy, Brit. J. Radiol., 25: 662-4 (1952).

(b) J. L. Morton, G. W. Callendine, Jr., W. G. Myers, Radioactive Co^{60} in plastic tubing for interstitial radiation therapy, Radiology, 56: 553-60 (1951).

(c) G. W. Callendine, Jr., J. L. Morton, W. G. Myers, Physical considerations in applying Co^{60} to cancer therapy, Nucleonics, 7(6): 63-6 (December 1950).

100. (a) J. Becker, K. E. Scheer, Strahlentherapeutische Anwendung von radioaktiven Kobalt in Form von Perlen, Strahlentherapie, 86: 540-7 (1953).

(b) W. Bickenbach, H. Gärtner, U. Zoeppritz, Die intrauterine Anwendung von Radio-Kobalt-Perlen, Strahlentherapie, 97: 188-93 (1955).

101. K. E. Scheer, W. Schwab, W. Ey, Kritische Bermerkung zur Kontaktbestrahlung mit Co^{60} in der Oto-Rhino-Laryngologie, Strahlentherapie, 104: 398-404 (1957).

102. (a) A. Doscherholmen, P. S. Hagen, Radioactive vitamin B_{12} absorption studies. Results of direct measurement of radioactivity in the blood (abs.), J. Clin. Investigation, 35: 699 (1956).

(b) R. F. Schilling, D. V. Clatanoff, D. R. Korst, Intrinsic factor studies. III. Further observations utilizing the urinary radioactivity tests in subjects with achlorhydria, pernicious anemia, or a total gastrectomy, J. Lab. Clin. Med., 45: 926-34 (1955).

103. Y. Stein, Detection of space-occupying lesions of the liver by directional counting of Co^{60}-labeled B_{12}, J. Lab. Clin. Med., 56: 290-3 (1960).

104. B. T. Eberle, I. Gleason, Radioisotopes of cobalt and vitamin B_{12} (abs.), J. Nucl. Med., 1: 60 (1960).

105. J. C. Sisson, W. H. Beierwaltes, Radiocyanocobalamine ($Co^{57}B_{12}$) concentration in the parathyroid glands, J. Nucl. Med., 3: 160-6 (1962).

106. (a) F. Comas, M. Brucer, First impressions of therapy with Cs^{137}, Radiology, 69: 231-5 (1957).

(b) M. Brucer, Teletherapy design problems. I. Cs^{137}, USAEC Report TID-5086, 2nd rev. (1955).

107. H. F. Freundlich, J. L. Haybittle, R. S. Quick, Radioiridium teletherapy, Acta Radiol., 34: 115-34 (1950).

108. Item in Nucleonics, 20(10): 31 (October 1962).

109. E. Calloway, The proposed adaptation of an Ir^{192} industrial radiographic unit for use in interorificial therapy (abs.), J. Nucl. Med., 2: 243 (1961).

110. (a) N. E. Chase, H. L. Atkins, J. W. Correll, Interstitial irradiation of brain tumors with Ir^{192}, Radiology, 77: 842-3 (1961).

(b) L. M. Liegner, Blind-end technique for Ir^{192} removable nylon ribbon interstitial implants: Application to carcinoma of rectum and vagina, J. Nucl. Med., 3: 255-67 (1962).

(c) R. D. Brasfield, U. K. Henschke, New technic for treating internal mammary node metastases in breast cancer, N. Y. State J. Med., 61: 3817-9 (1961).

(d) U. K. Henschke, Interstitial implantation in the treatment of primary bronchogenic carcinoma, Am. J. Roentgenol. Radium Therapy Nucl. Med., 79: 981-7 (1958)

(e) R. D. Brasfield, U. K. Henschke, Intravascular irradiation of the internal mammary lymph nodes in breast cancer, Am. J. Roentgenol. Radium Therapy Nucl. Med., 85: 549-59 (1961).

111. E. Syphers, R. Adams, D. Hinshaw, R. Nelson, W. L. Stilson, I. C. Woodward, Measurement of gastric emptying rates in the dog with Ir^{192}-labeled resin suspension and external counting, J. Nucl. Med., 1: 174-9 (1960).

112. L. E. Jacobson, W. N. Miller, W. R. Hillsinger, F. S. Einstein, Use of tumor and brain phantoms in the interpretation of positron annihilation and unbalance scans of brain tumors, Am. J. Roentgenol. Radium Therapy Nucl. Med., 88: 339-49 (1962).

113. J. R. Mallard, J. F. Fowler, M. Sutton, Brain tumor detection using radioactive arsenic, Brit. J. Radiol., 34: 562-8 (1961).

114. (a) E. R. King, M. W. Mason, N. B. Messinger, H. C. Dudley, A preliminary report on the use of Ga^{72} in clinical tracer studies,

Radiology, 59: 844-7 (1952).

(b) M. Brucer, G. A. Andrews, H. D. Bruner, A study of Ga^{72}. Summary and conclusions, *Radiology*, 61: 534-6 (1953).

115. M. W. Greene, W. D. Tucker, An improved Ga^{68} cow, *Intern. J. Appl. Radiation Isotopes*, 12: 62-3 (1961).

116. I. Ariel, J. S. Robertson, Irradiation with interstitial radioactive palladium (abs.), *J. Nucl. Med.*, 3: 194 (1962).

117. (a) L. Cohen, Protracted interstitial irradiation of tumors using Ta^{182}, *Brit. J. Radiol.*, 28: 338-40 (1955).

(b) W. K. Sinclair, Artificial radioactive sources for interstitial therapy, *Brit. J. Radiol.*, 25: 417-9 (1952).

(c) D. M. Wallace, J. R. Stapleton, R. C. Turner, Radioactive tantalum wire implantation as a method of treatment for early carcinoma of the bladder, *Brit. J. Radiol.*, 25: 421-4 (1952).

118. R. Teplitz, B. W. Fox, M. S. Littman, A. Littman, Intragastric beta irradiation with $Ru\text{-}Rh^{106}$ in human subjects: Results with single doses, *J. Nucl. Med.*, 2: 187-99 (1961).

119. G. C. Kyker, W. M. Christopherson, H. F. Berg, M. Brucer, Selective irradiation of lymph nodes by radiolutecium (Lu^{177}), *Cancer*, 9: 489-98 (1956).

120. (a) J. R. Andrews, W. N. Miller, W. R. Hillsinger, F. S. Einstein, The effects of 1 curie of S^{35} administered intravenously as sulfate to a man with advanced chondrosarcoma, *Am. J. Roentgenol. Radium Therapy Nucl. Med.*, 83: 123-34 (1960).

(b) R. G. Gottschalk, Radioactive sulphur in chondrosarcomata, *J. Bone Joint Surg.*, 42a: 1239-57 (1960).

(c) R. R. Lund, R. G. Davis, S^{35} therapy of mycosis fungoides (abs.), J. Nucl. Med., 3: 230 (1962).

121. C. T. Knorpp, H. M. Rennie, D. R. Korst, Radiosulfur (S^{35}) labeled Congo red dye, J. Nucl. Med., 1: 23-30 (1960).

122. M. Blau et al., mentioned in New Scientist, 16: 134 (1962) (item picked up from Medical Tribune).

123. (a) P. J. Talso, M. F. Glynn, Dilution studies of K^{42}, Na^{22}, and tritium in familial periodic paralysis (abs.), J. Nucl. Med., 3: 231 (1962).

(b) F. S. Hoffmeister, Timing of transfer flaps in reconstructive surgery, Surg. Gynec. Obst., 108: 68-74 (1959).

(c) J. N. Barron, N. Veall, Application of radioactive sodium to problems in plastic surgery, Brit. Med. Bull., 8: 197-202 (1952).

(d) G. B. Forbes, A. Perley, Estimation of total body sodium by isotopic dilution. I. Studies on young adults; II. Studies on infants and children, J. Clin. Invest., 30: 558-65; 566-74 (1951).

(e) R. J. Walton, W. K. Sinclair, Radioactive solutions (Na^{24} and Br^{82}) in the treatment of carcinoma of the bladder, Brit. Med. Bull., 8: 158-64 (1952).

124. (a) H. K. Awwad, A. W. G. Goolden, The uptake of radioactive K by red cells in various thyroid states, Clin. Sci., 20: 113-22 (1961).

(b) R. Smith, J. C. Waterlow, Total exchangeable K in infantile malnutrition, Lancet, 1960-I: 147.

(c) F. K. Bauer, N. Telfer, J. Lestina, M. A. Jenkins, Total exchangeable potassium determination in saliva using K^{42} and Rb^{86}, J. Nucl. Med., 1: 199-203 (1960).

(d) I. T. Nathanson, W. H. Baker, B. Selverstone, Radioactive K (K^{42}) in the study of benign and malignant breast tumors (abs.), Proc. Am. Assoc. Cancer Res., 1: 140 (1953).

125. E. A. Carr, Jr., W. H. Beierwaltes, A. V. Wegst, J. B. Bartlett, Jr., Myocardial scanning with Rb^{86} (prelim. note), J. Nucl. Med., 3: 76-82 (1962).

126. A. Croak, H. Duncan, B. Gutteridge, C. Pallis, Use of Br^{82} in differential diagnosis of lymphocytic meningitis, Brit. Med. J., 1960-I: 704-6.

127. J. P. Nicholson, J. F. Zilva, Estimation of extracellular fluid volume using radiobromine, Clin. Sci., 19: 391-8 (1960).

128. P. F. Hahn, G. Rouser, H. Brummitt, J. Moorehead, E. L. Carothers, The drainage of radioactive silver colloids by the lymphatics following intrapulmonary administration in dogs, J. Lab. Clin. Med., 39: 624-8 (1952).

129. W. A. Reilly, K. G. Scott, G. L. Searles, The clearance of Ag^{111} from plasma and liver of cirrhotic and noncirrhotic patients, J. Nucl. Med., 1: 191-4 (1960).

130. P. Czerniak, A. Naharin, N. Alexander, Turnover rates of zinc in the body as determined by the study of Zn^{65} in rats, Intern. J. Appl. Radiation Isotopes, 13: 547-56 (1962).

VIII. SAFETY