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A CRITICAL REVIEW OF BIOLOGICAL
ACCUMULATION, DISCRIMINATION AND
UPTAKE OF RADIONUCLIDES IMPORTANT
TO WASTE MANAGEMENT PRACTICES

1943-1971

DECEMBER 1971

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A Critical Review of Biological Accumulation,
Discrimination and Uptake of Radionuclides
Important to Waste Management Practices
1943-1971

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December, 1971

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ABSTRACT

The objective of this survey is to screen the world literature for data on biological uptake and accumulation or the discrimination against uptake of certain radionuclides associated with nuclear waste management. Historical aspects based on the publication sequence of biological research are briefly considered, and relevant research findings are discussed under several categories. One category is devoted to transuranic elements and is accompanied by a special bibliography. The application of research findings to the Hanford situation is discussed and projects for future study are recommended. An annotated list of 119 references is presented.

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INTRODUCTION

The uptake of radioactive elements by plants and animals has been of scientific interest and medical importance for many years, but only since World War II and the development of atomic energy has study intensified. During these years also, an improved understanding of the movement of radioactive elements in natural systems was gained from studies on mineral cycling and energy flow. There have been concentrated efforts in two areas: (1) the development of techniques to prevent and detect the spread of radioactive contamination which is possible from various nuclear activities, and (2) to predict the fate of radionuclides upon their release or escape into the environment and subsequent incorporation into ecological systems. Radioactive contamination can be hazardous to man either as a result of direct contact, ingestion, or inhalation, or, in an indirect manner through environmental contamination within his ecosystem.

The chronology of research effort on the uptake and retention of radionuclides has, to some degree, shaped our knowledge of the behavior of radioactive elements in biological systems and the environment. The generalized sequence of research activity is summarized from the literature and listed in Table 1. The early years of the nuclear industry were governed by national security considerations, and emphasis was placed on using the natural properties of soil to store radioactive wastes generated by nuclear processing plants. Some biological data were collected, but most studies were in the interest of hazard evaluation for nuclear workers and the public at large.

Table 1. The general sequence of biological studies concerning the fate of radionuclides in biological systems.

Time period	Types of studies conducted
Post War to mid-1950's	Emphasis on waste disposal to the ground; demonstration of fission product uptake by plants and animals; establishment of MPC's; development of "delay and decay, concentrate and contain, and dilute and disperse" philosophies.
Mid-1950's to mid-1960's	Emphasis on fallout from weapons testing; reactor effluent studies show importance of biological concentration processes; beginning of lab studies on fate of radionuclides in plants and animals following soil uptake or injection, ingestion and inhalation. Most prolific period of biological studies.
Mid-1960's to present	Food web transfer and ecosystem studies; the mechanisms of uptake and retention of radionuclides; medical application of radioactive materials; radiation effects on biological systems.

Studies within the second major period were dominated by concern over the fate of fallout. At this time the importance of long lived strontium-90 and cesium-137 as hazards to biological systems was emphasized, and biological concentration was demonstrated as a phenomenon to be reckoned with. By the end of this period, laboratory studies were well underway on the fate of radionuclides within the animal body following injection, ingestion or inhalation, and much information was to be gained on the critical body organ for each radionuclide. Most of the information available today on the direct uptake by animals as well as the behavior of radionuclides in plants was published during this period. Important review books and proceedings of national or international conferences also were completed at this time.*

* Especially see: Reference numbers 7 and 51 and Aberg, B. and F.P. Hungate (eds.). Radioecological Concentration Processes. 1967. Proceedings of an International Symposium, Stockholm, April, 1966. Pergamon Press, New York, N.Y.

The main feature of the last historical period involves food web transfer studies. Field studies, particularly of aquatic habitats, showed an increase in radionuclide accumulation with succeeding transfers through food webs. Detailed studies were continued on the mechanisms of radionuclide uptake and retention. Current study trends are towards a greater understanding of biological phenomena using radioactive tracers; peaceful uses and applications of radiation and radioactive materials; and long term maintenance of previously contaminated areas and the management of radioactive wastes.

EVALUATION OF THE LITERATURE

Many papers have been written about biological accumulation or discrimination, and results from much of the older works were recorded in obscure government publications. The annotated list presented here probably is not exhaustive, but it certainly represents more than 95% of the pertinent literature. Because of the increase in the number of journals and special reports in recent years, there is some possibility of missing a very current and perhaps significant finding.

Literature references were selected to meet the following criteria and thus keep them relevant to the purpose of this review. The report had to be related to some aspect of nuclear waste management which meant that it was concerned with one or more radionuclides of the following elements: strontium, cesium, ruthenium, cobalt, antimony, cerium (praseodymium), zirconium (niobium), promethium, technetium, or plutonium and other transuranics. Tritium and uranium are briefly considered in some reports*. Moreover, field studies on wild animals or native plants were considered more important than those concerning laboratory animals and crop plants, and information on freshwater habitats was considered more important than that on marine situations. Most studies on fallout were excluded for a number of reasons but primarily because of the uncertainty of particle chemical composition and the mode of biological availability of radionuclides. Reports on biological uptake of reactor effluents were largely ignored because short-lived activation products rather than fission products are involved. Studies on leaf uptake or hair and epidermal contamination were mostly omitted, and injection and acute inhalation studies were

*See bibliography numbers 68, 73, 89, 101, 110, 111, 112

usually not considered. However, ingestion and feeding experiments were included if of sufficient duration for the radioelement to be considered at equilibrium by the end of the study period. Reports of most interest were those concerning uptake by the native flora and fauna at actual waste management operations. Unfortunately there are not many such studies reported, especially for terrestrial systems. Informative review articles, especially those with new data, are included*, but usually the original sources of information were sought. Literature evaluation is tailored to the Hanford situation which should apply equally well to other locations with similar ecological and waste disposal histories. Selected information from the survey is discussed under the following six synoptic categories. Pertinent abstracts for each citation are presented in the last section.

I. Uptake of Environmental Radionuclides by Organisms:

Radionuclide uptake by organisms is the rule and in many cases true biological accumulation** occurs, although large species and varietal differences have been recorded. Early studies concerned with demonstrating plant uptake of fission products and other radionuclides showed rather conclusively that different plants had different capacities for uptake and accumulation.^{5,7} Additional studies, designed to investigate species^{46,115} and varietal⁶⁰ differences, quantified the relationships in many cases. By and large those species or groups (e.g. plant family Chenopodiaceae) known to accumulate or tolerate the presence of salts also accumulate radionuclides. Some plants like tumbleweed (Salsola kali) and pond weed (Myriophyllum spicatum) exhibit uptake through a mechanism whereby strontium oxalate crystals are formed in the tissue.^{3,15}

* See reference numbers: 23, 32, 33, 39, 44, 45, 56, 58, 66, 70, 76, 78, 86, 109, 116

** The concentration of a radioelement in the tissues of an organism which exceeds that found in the physical environment.

Similar phenomena and the formation and uptake of organic acid complexes are suspected for other plants.^{1,4} Animals, particularly insects⁸⁵ and fish,¹³ were found to accumulate radioelements in various tissues. The accumulation of ⁹⁰Sr and ⁶⁰Co into hard tissues of bone, shell, or exoskeleton is significant to ecosystems because it represents a biological sink which tends to remove the radionuclide from the system. However, some studies have shown that animal consumption of these tissues leads to an increase in the body burden of the consumer and thus represents an ingestible source of concentrated radionuclides.⁵⁴ A study at White Oak Lake, Tennessee (ORNL), showed that winter bird populations feeding in contaminated areas had greater body burdens of strontium and cesium than other populations. The reason was traced to the consumption of contaminated soil by the winter inhabitants while searching for seeds.³⁸ The incidental consumption of radioactive materials is an important observation and could easily be overlooked in a strict food web pathway approach to studying biological concentration processes which operate under natural conditions.

In addition to physiological means of accumulation, physical phenomena such as surface absorption into mucilaginous coatings are important particularly with small organisms (e.g. unicellular algae) which have very large surface-to-volume ratios. Many plants exhibit distribution or concentration gradients within their bodies at least for some radionuclides. This is especially true of the rare earth elements and results in adsorption to root surfaces with poor translocation following such root uptake.

Leaf tissue commonly has the highest concentration of strontium and cesium within the plant body.¹⁸ Plant tissue concentrations of radionuclides normally are a function of soil or water concentration and solubility of the radioactive salt for any given system, however, it is very difficult to predict plant concentrations to within several orders of magnitude from only a knowledge of environmental concentration. This is due to environmental interactions, age and prior history of the organism, differences in physiology, and the behavior of the radionuclide in the environment depending on physical and chemical properties of the contaminant and the substrate. In the latter category, the calcium status of the substrate has a profound affect on strontium, i.e., high calcium tends to suppress strontium uptake by plants or animals. Normal agricultural applications of calcium to an acidic soil

reduced plant uptake of strontium by 80 percent, whereas, no such calcium effect was noted for a neutral-fertile soil or an alkaline-calcareous soil.²⁸ For different freshwater lakes it was determined that when water calcium increased by a factor of 100, the strontium concentration factor* of fish flesh decreased by a factor of 100.⁸²

The generalized decreasing order of terrestrial plant uptake and subsequent translocation to shoot tissue established by laboratory and field studies is $Sr \gg Cs, Ru > Co > Sb, Ce(Pr), Zr(Nb), Pm > Pu$.⁴⁴ The relative position of Tc is unknown. Broad leaved plants may have a slightly greater ability to take up radionuclides than grasses¹² although a distinction is difficult when strontium uptake, for example, is based on calcium uptake.⁴⁶ By and large the ratio of calcium to strontium in the plant (or animal) is quite similar to the ratio of the same elements in the substrate (or animal food). Cesium, apparently, is readily taken up by all plants and animals, even surpassing strontium, when it is in an available form and not sorbed to soil colloids.⁵⁷ Gastrointestinal absorption of cesium can be 100% in some animals.⁴⁰ Cobalt is an essential nutrient element and suspected of being accumulated for that reason by blue-green algae inhabiting a waste pond.⁹³ Some plants apparently have physiological mechanisms which truly exclude the uptake of a specific element. Water lily (*Nuphar variegatum*) has been noted to take up 10 times less strontium than calcium relative to water concentrations. It was the plant in which the greatest discrimination against strontium was noted.¹¹⁵ Discrimination against an element, when it can be demonstrated, is thought to occur through root absorption mechanisms as well as mechanisms associated with translocation to the above ground parts of the plant.

II. Uptake of Environmental Radionuclides into Ecosystems (food webs):

Aquatic systems have received the most attention primarily because of (1) their importance to reactor effluent discharge and low level waste disposal, and (2) their ease of study compared to terrestrial systems. Much information on ecosystem behavior (dynamics) has been gained from studies on fallout radionuclides or the fate of activation products (³²P, ⁶⁵Zn and ⁶⁰Co) following discharge into river systems. Early work in the latter category demonstrated that large CF values were possible

* Concentration Factor (CF) = $\frac{\mu Ci/gm \text{ organism}}{\mu Ci/gm \text{ substrate}}$

and that accumulation processes frequently increased along food chains to the last consumer organism. Animal body burdens are governed by food habits, size of the contaminated area, home range or for migratory animals the length of stay, and the physiological ability of the animal to retain the radionuclide. Observations on fallout radionuclides in reservoir water indicate the possibility of a contamination pathway either via fish or drinking water leading to man.⁹¹ Russian studies on ore deposits show that uranium as well as radium and thorium are taken up by plants (radium > uranium > thorium) and move through food chains but at very slow rates.¹⁰¹ Uranium may be discriminated against at each transfer step in aquatic systems.⁸⁹

Strontium and cesium have been studied in ecosystem situations more than any other radionuclides because of their ubiquitous distribution from fallout, relatively high availability to organisms, and long half-lives relative to other fission products. Specialized situations concerning low level waste disposal operations at Hanford, Chalk River (Canada) and especially ORNL have also attracted attention. Bluegill and black crappie in White Oak Lake showed uptake of all nuclides present in the water, especially strontium.¹³ Strontium accounted for 90% of the activity found in hard tissue, whereas, cesium and ruthenium were 75% and 10%, respectively, of the activity in soft tissue. Other radioelements absorbed were cobalt, cerium (Ce-Pr), and zirconium (Zr-Hf), but none accounted for more than 3% of the total activity taken up. The uptake of radionuclides was highest in summer and lowest in winter reflecting the availability of contaminated food sources.

The abandonment of the lake as a disposal area and subsequent exposure of the lake bed and colonization by plants provided a unique opportunity to study the behavior of radionuclides in terrestrial environments. Studies indicated that plant uptake was governed by a large number of factors,^{42,57} but once the radionuclide was extracted from the soil it was rather easily transferred from one ecosystem level to another.⁴⁸ Living plants not only provided food for herbivorous mammals and large insects but they also provided a litter substrate for minute soil inhabiting animals (insects and other arthropods) and eventually, through decomposition, a source of

radionuclide for recycling to plants. These studies were conclusive in implicating plants as the backbone of the ecosystem and the principle source of essential minerals and radionuclides (and energy) to animals and decomposer organisms. Plant-insect transfers, for example, indicated 10% of the strontium and 80% of the cesium may be retained by grasshoppers feeding on contaminated smartweed (Polygonum spp.).⁵⁵ Retention differences are apparently due to the lower rate of elimination of cesium than strontium in the species of grasshopper studied.⁴¹ Litter and soil inhabiting animals (herbivorous and predaceous arthropods) may accumulate greater proportions of cobalt and especially ruthenium than cesium,¹⁰⁷ and predaceous arthropods are capable of converting up to 100% of the cesium and 10% of the strontium found in their prey.⁴⁰ Ruthenium is suspected of becoming more concentrated than cesium in terminal links of food chains.

The saving feature of arthropod populations (including insects) in preventing them from becoming a major nuisance factor in the spread of contamination away from low level disposal areas is their small total biomass (standing crop).⁴⁰ For the ORNL area, it was estimated that if all insects were to leave the waste disposal site at one time they would remove only the amount of strontium present in 10 kg of soil.⁵⁵ However, insects are mobile and the total amount of a radionuclide that could be removed from an area over a prolonged period of time would be greater and in accord with their annual productivity of biomass. The major problem with insects and other small animals is their potential as continual sources of contaminated food to larger animals, particularly waterfowl.

The movement of tritium through food chains has also been noted in terrestrial ecosystems. Residual tritium at the sedan crater (Nevada Test Site) was found to permeate the simple ecosystem which had developed within 2 years.¹¹² Tritium concentrations in tissue and tissue water of tumbleweed and heteromyid rodents were very similar to those of soil water, and it was concluded that tritium may be considered one of the most biologically significant radionuclides in an arid climate because of its rather complete involvement in all levels of the ecosystem.

Many investigations on the uptake and transfer of radionuclides in aquatic food webs have been conducted under field as well as controlled

conditions. Almost all studies have demonstrated accumulation along food webs to the last consumer organism. Another characteristic feature of aquatic systems is accumulation in sediments relative to water concentrations.¹¹¹ It is recognized that radionuclide uptake by fish can occur directly from contaminated water, but apparently ingestion of contaminated food is the most important source under conditions of low level water contamination.¹⁶ The body burden of different fishes, under natural conditions, usually reflects their diet, thus, different fishes may show different radionuclide concentrations when living in the same environment.⁷⁵ The CF (flesh) for cesium increased several-fold within a three-link fish to fish predator chain and 9 times from water to top consumer.⁸⁷ Cesium is also readily accumulated in food webs leading to water fowl. Flesh concentration factors of more than 2000 have been recorded at Hanford for mallard ducks.²⁶ Another unique feature of aquatic systems is the uptake and accumulation by filter-feeding animals (e.g. clams) of a radionuclide like cesium which is relatively unavailable in terrestrial systems.¹⁰⁸ The reason is that the radionuclide is sorbed onto particulate matter in the water and thus is made available in concentrated form. A very recent study indicates that cobalt-60 was associated with $>1.2\mu$ particles in lake water.¹¹⁹ The through-flow lake had a 30% retention capacity, and more than 90% of the cobalt activity in the lake was located in the upper 30 cm of sediments.

III. Data Comparison and Interpretation of Results:

Early studies must be evaluated carefully, particularly when an attempt is made to apply the results. Results from the earliest studies on strontium uptake were not comparable because the influence of calcium status on strontium uptake was not understood at the time. This led to the use of "observed ratios" (OR), or "discrimination factors" (DF)* which compare strontium uptake to the simultaneous uptake of calcium.^{9,20} A similar kind of relationship for cesium and potassium was thought to

*

OR or DF = $\frac{\text{Sr/Ca Acceptor}}{\text{Sr/Ca precursor}}$ Values less than 1.0 indicate a discrimination against the uptake of strontium, relative to calcium, by the acceptor (plant or animal).

exist but has been mostly discounted. Caution should be exercised in the use of element pairs or ratios of pairs in evaluating food webs because the relationships between the elements may vary from organism to organism.³² Where soils contain excess calcium, such as at Hanford, the use of OR values in predicting strontium uptake is unnecessary and the expression of strontium uptake as a ratio with calcium in leaf tissue is sufficient to identify species characteristics because strontium uptake cannot be modified by additional calcium. The use of stable element ratios (specific activities) also has been recommended for predicting the fate of radionuclides in the environment,⁶⁶ but with situations where chronic contamination is known to occur it is easier to measure directly the radioactive contaminant. The most widely used means of expressing data is the "concentration factor" (CF) which is quite satisfactory if its usage is defined. It has been suggested that "relative concentration" is a more precise term.⁸² However, it is common for wet weights, air dry weights, or oven dry weights (either 60 or 105 C) to be used without specification. There can be more than a 90% difference between wet weight and oven dry (105 C) weight values. Moreover, in food web studies CF's may be based on the contents of the original water, soil substrate, or a food source, and result in orders of magnitude differences in CF values. The major drawback to the utility of CF values lies in estimating the availability of the radionuclide for uptake by plants. It is impossible to synthetically duplicate the soil extraction process inherent to plants and thus determine the amount of radionuclide available. Various extracting solutions have been used as well as measurement of the total amount present (or added). The problem is particularly serious for cesium. Some usefulness can be made of food web relationships when CF's are based on plant concentrations and thus circumvent the soil uptake problem. A similar situation exists in aquatic systems where acute releases to water may remain in solution for only a few weeks. Resulting CF's based on water values, thus, are inherently high and misleading. The problem is not quite as serious under chronic release situations, but uptake from sediments must also be taken into account.

Early data were frequently reported as per cent uptake of dose, e.g. plants growing in pot culture may take up 1.0% of the dose.²⁴ These data

are not convertible to CF's because of the need for weights and they may be subject to bias.

There have always been problems with extrapolating laboratory-derived data to field situations. The Neubauer technique in determining plant uptake of radionuclides was widely used at one time, and such data must be examined with caution. The biggest drawback probably is the short duration of the experiment, for uptake and distribution within the plant is suspected of being age dependent.^{84,92} Solution-culture (hydroponic) techniques for rearing plants also are widely used but represent a very unusual environment for terrestrial plants. Comparison studies and those designed to investigate plant physiology may be valid, but other studies have shown as much as three orders of magnitude greater plant uptake of radionuclides from solutions when compared to soil uptake under similar laboratory conditions.¹²

A study on the uptake of cesium by plants when only the substrate was varied indicated decreasing availability in the order: solution culture > clay suspension > water saturated soil > irrigated soil.⁶⁰ Supposedly even greater discrepancy would be found under field conditions, especially for cesium which is fixed tenaciously to soil colloids. Leaf-root ratios have been proposed as a means of comparing uptake of different radionuclides and plant species.⁸ The value of the ratio, however, does not seem to outweigh the difficulty of accurately obtaining such data, and the expression is not widely used.

Perhaps the greatest difficulty in evaluating early data lies in the tremendous changes which have taken place with radioassay techniques over the past 30 years. Cesium and ruthenium are known now to be volatile when heated, and almost certainly the very early interpretation of their unavailability for plant uptake and food web transfers is questionable because of the manner in which samples were prepared for analyses. Recent studies attach importances to these radionuclides not previously recognized. Studies on ruthenium escapement to White Oak Lake bed indicate that its availability to the ecosystem is second only to strontium.¹⁰⁷ A study in Florida on fallout cesium indicates that cesium in the food chain leading to man is more important than strontium for that peculiar area, where soils

do not readily fix cesium.¹¹⁸ Another improvement in radioassay technique has been the increased sensitivity and resolution available from modern electronic equipment. It would be profitable to confirm some of the early findings relevant to low level liquid waste management. Plant uptake of fission products from waste line leakage into soil revealed 20 years ago that cesium constituted less than 1% of the total plant uptake activity.³ This is inconsistent with modern results and probably reflects the early practice of flaming sample planchets prior to counting.

The use of indicator organisms, i.e., those that are particularly sensitive to the presence of radionuclides and accumulate them from the environment, also poses a problem to ecological evaluation. Biological monitoring programs⁷² find indicator organisms very useful in locating the spread of hazardous radioactivity from a nuclear installation, but the data are generally unsuitable for quantitative purposes. Species and environmental differences introduce major variables not accounted for.¹⁰⁵ In cases of known chronic release, a direct investigation of the species involved and their levels of contamination is much preferred to inference drawn from indicator species.

IV. Effects of location and environmental factors on uptake:

The location of radionuclides within the ecosystem and physical features of the environment are ecologically important to the uptake and distribution of contaminants. Aquatic systems usually develop two general areas of radionuclide concentration under chronic contamination conditions. Particulate matter suspended in the water (non-living solids as well as minute plants and animals, i.e., plankton) is capable of accumulating sizable quantities of radionuclides relative to water concentrations because of large sorption surfaces and biological uptake. Cobalt-60 has been noted to be associated primarily with colloidal sized particles, but some of the largest CF values involve the sorption of zirconium by algae.³¹ The phenomenon is accentuated when filter-feeding animals (clams) are present, and the strontium CF (shell-water) can be as much as 65000.⁴⁹ The second major source of radioactivity, that accumulated in sediments, is the result of biological processes (death and subsequent settling out of organisms) and physical processes (precipitation and adsorption to inorganic particles

followed by settling out). An early study on a controlled pond at Hanford showed that the cesium CF for water-sediment could easily reach 10,000.²⁶ Studies on reservoirs indicate that fallout strontium and other radioactive materials accumulate in sediments.

A recent study on algal (periphyton) growth in White Oak Lake showed that algae growing near the lake bottom contained greater concentrations of ruthenium, cesium, and especially cobalt than those growing near the surface.⁹³ Water concentrations of the radionuclides was apparently greater near the bottom due to resuspension and resolution of sediments. An interesting study at NRTS examined the possibility of the formation of strontium or cesium organic complex molecules following decomposition of contaminated algae.⁷⁴ Organic complexes would be expected to reduce soil sorption, however, no differences in K_d values* were apparent when either fresh or decomposition sources of radionuclides were used. However, plant uptake studies were not conducted and other radionuclides were not tested. Studies at ORNL revealed that an algal culture (Euglena) could sorb 96% of the added cesium within 34 days regardless of water concentration up to 10 $\mu\text{Ci/l}$.²⁷ Both living and dead algal cells sorbed the radionuclide.

Early studies regarding placement depths of radionuclides in soil profiles came from interest in the fate of fallout and possible amendment procedures to reduce availability. It has been determined that the effect of soil placement depends on rooting pattern which is mostly a plant characteristic. Observations on plant uptake from White Oak Lake bed where strontium, cesium, ruthenium, and cobalt were concentrated in the upper 4 in. of soil, indicated that the radionuclides were readily taken up by smartweed (Polygonum spp.) and goldenrod (Solidago spp.).⁵² Experimental results from Los Alamos showed that plant uptake of cesium from 60 in. deep cylinders decreases as the percent of contaminated soil (by depth) decreases.³⁹ Presumably this is a function of the number of roots in contact with contaminated soil relative to roots in contact with non-contaminated adjacent soil. On the other hand when soil is

* Distribution coefficient (K_d) = $\frac{\text{pCi/gm soil}}{\text{pCi/ml water}}$ upon equilibrium

contaminated, as from fallout, and contains strontium or cesium activity at the surface, plant uptake (ryegrass) may be enhanced compared to deeper placement in the profile.³⁷ Similar results were obtained when mixed fission products were added either to the soil surface or throughout the culture pot, i.e., wheat uptake was greatest from surface applications where concentrations were highest.⁶¹ When rice was grown in containers flooded with water and cesium placed at the soil surface, uptake was 6 times greater than when the radionuclide was mixed uniformly in upper 6 in. of soil.¹⁰⁶ Thus, it appears that conditions which produce a moist and contaminated soil surface are conducive to plant uptake.

Studies reported on the leaching and removal of strontium and cesium from intact leaf tissue are important in view of the demonstrable increase in uptake from soil surface contamination.¹⁰² An early experiment on the subject using potted geranium plants readily showed that strontium and many other cations as well as anions are easily leached from leaves with water.⁴⁵ In addition, plant mechanisms are such that materials are replenished to the leaves. The implications of these findings are important when considering the establishment of a cover crop with aid of sprinkler irrigation in order to stabilize a shallow soil covering a contaminated surface. Not only does water leach undesirable materials from leaves, but also the natural shedding of contaminated leaves may have a profound effect on the spread of contamination. Cesium derived from litter, for example, is available for uptake by plants as well as other components of the ecosystem and results in a self-perpetuating circulation of the radionuclide.⁶⁷

A few studies have investigated or observed the effects of light and temperature on uptake. Corn plants grown in soil under 50 F to 80 F extremes showed that the greatest uptake of strontium or cesium occurred at 70 F, whereas, zirconium uptake was below detection limits at all temperatures.⁴⁷ Similarly, strontium uptake by barley or beans was reduced when root temperatures were lowered from 63 F to 44 F.³⁶ Decreasing the light intensity and shortening the light period (photo-period) also reduced strontium uptake. These results agree with studies of environmental influences on plant nutrition. Observations on a small pond constructed

at Hanford to study waste disposal practices, indicated that cesium uptake was greatest when water temperature was most favorable for aquatic plant growth.²⁵ The shading influence of floating algal mats reduced cesium uptake by submerged aquatic plants by as much as two-thirds. Emergent aquatic plants sorbed cesium directly from the water as well as via root uptake from gravel or mud substrates.

The necessity of oxygen in the root zone for proper uptake of plant nutrients has been recognized for some time, however, when oxygen tensions were altered during uptake studies of cesium and cerium the data showed little more than species differences in response.⁷¹

V. Effects of soil ammendments on radionuclide uptake:

Perhaps the most voluminous data on any one topic, especially from early years, is the influence of substrate chemical composition on plant uptake. Major subjects of interest have been concerned with calcium, stable isotopes, nutrients, organic matter and water. Of greatest practical significance is calcium supression of strontium uptake, because, liming of acid soils was found to reduce the uptake of fallout strontium by nearly half.³³ The magnesium status of some acid soils may be equally important in strontium relationships. Where soils were more than 80% base saturated, however, additional calcium had little or no influence on strontium uptake by wheat.¹² Uptake by pea plants was significantly reduced and agrees with known calcium requirements of legumes. Similarly, for aquatic systems an increase in water substrate calcium or magnesium will decrease strontium uptake by algae.^{50,98}

Normally, the addition of stable isotopes or analogs of the radionuclide of interest have the same suppressing influence as calcium on strontium uptake, i.e., a dilution effect, but cesium may be different which has to do with the way the element is fixed by soil colloids (primarily illitic clays). Cesium ions, and to greater or lesser degrees those of potassium, ammonium, and rubidium, are trapped into the crystal structure of the clays. Reverse reaction and the release of ions is slow, and if the lattice structure collapses the ion may be permanently trapped. One study indicated that the soil used had a finite number of fixing sites and as these were used up the availability of cesium for plant uptake increased.²⁰

The phenomenon may be particularly important to the management of chronic waste discharge sites and lead to an increase in cesium uptake into the biota with time. Unusual Florida soils with low cation exchange capacities, low cesium fixing capacities, and high sand contents showed cesium uptake by forage grasses and clover to be an order of magnitude greater than strontium.¹¹⁸

It is difficult to identify those soil factors which can account for most of the variation in plant uptake. For example, cesium uptake by a sedge (Carex frankii) growing in White Oak Lake bed had a correlation coefficient of about 0.5 for total soil cesium (0-2 in.), exchangeable cesium, calcium and magnesium (0-6 in.), and pH.⁶² This was the highest correlation obtained from a number of calculations, but a value of 0.5 indicates that the combined effect of these variables was not reliably correlated with cesium uptake by the sedge. In general, the addition of fertilizers merely increases plant growth and the total amount of radionuclides taken up increases, but CF's are rarely changed. Treatments with sulfate, carbonate, or oxalate salts of potassium were noted to promote a 30% increase in mean activity per unit weight for strontium uptake by ryegrass.⁸⁴ The enhancement of strontium uptake of oxalate is noteworthy because of the insolubility of strontium oxalate and the demonstrated decrease in uptake from strontium salts with decreasing solubility.³⁷ The mass action effect of calcium ion in the possible formation of calcium oxalate in soil solution instead of strontium oxalate, possible species differences, and possible stimulation by potassium on plant growth and strontium uptake all are plausible explanations. This problem should be clarified for the Hanford situation, because of the known accumulation of strontium by tumbleweed and formation of strontium oxalate crystals within the plant. Strontium released to the soil following the decay of contaminated tumbleweeds, thus, may be in a more readily available form.

Several studies indicate that the influence of organic matter on uptake of radionuclides is variable and probably different for each radionuclide. For example, the uptake of strontium from soil to which a contaminated crop residue was added was proportional to the amount added.¹⁰ Strontium uptake was about 2% of the total added and there was no difference

in uptake from top or root residue. Another study obtained similar results when either contaminated or uncontaminated organic matter was used except that very large additions of organic matter increased the carbon-nitrogen ratio and resulted in decreased growth and decreased strontium uptake.¹⁴ Results on cesium uptake from soils of varying organic matter contents suggested that cesium retention in soil was inversely proportional to soil organic matter content.⁶³ It was reasoned that when organic matter contents are low, the exchange capacity of a soil is almost entirely due to clays which fix cesium to a greater extent than organic matter. Thus, organic matter may compete with clay as a source of cesium binding sites, but availability from organic matter is greater than from mineral soil and greater uptake results.

Acting as a solvent, soil water is thought to be an important variable to radionuclide uptake. Vegetation zonation on White Oak Lake bed was such that differences in strontium and ruthenium uptake for smartweed (Polygonum spp.) and aster (Aster spp.) were considered to be a function of habitat; i.e., greater uptake of both radionuclides occurred in smartweed that grows in wet areas.⁵² A different species of smartweed (Polygonum persicaria) grown at Hanford showed a 450-fold increase in uptake of cesium when grown in a shallow pond as compared to uptake under irrigated conditions.³⁵ An intermediate "wet meadow" condition resulted in a 30-fold increase over irrigation. Uptake from the pond was attributed to absorption through adventitious roots in the contaminated water as well as directly through stem tissue. The experiment was conducted for 36 days only, a rather short period of time for a perennial species.

Time as a factor affecting radionuclide uptake has been considered, and a few long term studies have been conducted on strontium and cesium uptake. Over a seventeen month period, the CF for strontium in clover remained relatively constant, but as the uptake of potassium decreased, the uptake of cesium increased.²⁴ Eight years following a surface application, strontium availability had been decreased by about 10% and the strontium-calcium ratio decreased as strontium moved downward through the profile.⁷⁹ Fertilizer treatments had no effect on strontium uptake.

Cesium uptake, in a complimentary experiment, was unaffected by the addition of fertilizers but decreased during the first three years of cropping.⁸⁰ Uptake was relatively constant for the next three years. It was assumed that cesium fixation in this soil required three years to complete. When plants were grown on ejecta from the "Sedan" detonation at NTS, the uptake of strontium, cesium, ruthenium, cobalt, cerium, and antimony persisted over the three years study period.⁹⁶

VI. The Transuranic elements in soil, plants, and animals:

The transuranic elements generally have received only scattered attention regarding their behavior in the environment. However, the importance of plutonium in the environment and evidence of the AEC's compliance with the National Environmental Policy Act of 1969 are indicated by the formation of the Nevada Applied Ecology Group in 1970. The group established that the distribution, fate and significance of plutonium in the environment resulting from nuclear detonation tests was to be the first priority problem for study (Romney and Davis, 1971)*. Waste storage and disposal associated with fuel processing, however, are not only concerned with plutonium, but also other transuranic elements. McKay (1961) has pointed out that neptunium, plutonium, americium, and curium are the most significant and hazardous alpha emitters from reactor operations. The frequency and importance of these transuranic elements in waste streams will increase in the future when breeder reactor fuels are reprocessed. Health physics considerations have been reviewed by Denham (1969) who noted that all transuranics except neptunium have higher specific activities than plutonium. The internal health hazard of the transuranic elements has been studied extensively, but most information of a biological nature is available for plutonium and has been reviewed by Thompson (1967).

* References cited by name and date occur in a special bibliography at the end of this section because of only partial relevance to the objectives of this report. References cited by number are located in the Annotated Bibliography.

Soils

Problems associated with fallout plutonium in terrestrial environments have been reviewed by Krey et al. (1962) and Olafson and Larson,⁵⁸ but the environmental fate of other alpha emitting radionuclides is not well known. Langham et al. (1966) and Langham (1968) assessed the problem of plutonium contamination at the Nevada Test Site and elsewhere and suggested that the hazard to man was minimal as long as particles deposited on vegetation and soil remained deposited. Romney et al.¹¹⁷ observed a slight downward movement into undisturbed soil profiles at the Nevada Test Site during the 10 years following deposition. The solubility of plutonium fallout particles in the presence of soil is poorly understood, however, plutonium infiltration to a depth of 12 cm was attributed to the downward movement of the high density particles and not solubilization. Mork (1970) noted very similar downward movement in the same sampling areas 2 years post detonation where plutonium was found to be predominantly associated with $>44\mu$ particles. Krey and Hardy (1970) present results from a soil survey in the vicinity of Rocky Flats following a fire in 1969. Two samples were collected from horticultural soils in Denver and showed that 55% and 61%, respectively, of the plutonium in the first 20 cm of the profile was below 5 cm. These were the only samples to show such a distribution. More than 60% of the plutonium for the other six samples was located within the upper 5 cm of soil which are results similar to those described for northern Italy (de Bortoli and Gaglione, 1969). Cultural practices were suggested as the cause for deep penetration into the Denver city park soils.

The movement of plutonium in the soil environment from other than fallout sources also has been studied. Rhodes (1957a) reported on soil sorption of plutonium from aqueous solutions and noted that sorption was greater than 97% between pH 2 and 8. Higher pH resulted in reduced sorption presumably due to a chemical change associated with pH. Studies by Prout (1958) substantiated Rhodes' results and showed that the sorption phenomena also is dependent on oxidation state. Jacobson and Overstreet² showed previously that sorption to Ca-bentonite clay suspensions was valence dependent where $\text{Pu}^{+3} > \text{Pu}^{+4} > \text{PuO}_2^{+2}$. Andelman and Rozzell (1970) thoroughly discuss the chemical behavior of plutonium in the water environment and note

the various valence states possible in aqueous solutions. Plutonium hydrolysis products exhibit colloidal behavior, and pseudocolloids may be formed when sorption onto other materials occurs. Moreover, colloidal sized particles increase in size when (one) the pH of the solution is increased, (two) the solution is heated, (three) the solution is aged for several months, and (four) ionic strength is increased. Reverse reactions are very slow even in the presence of solubilizing complexing agents. Colloidal plutonium IV ($\text{Pu}(\text{OH})_4$) is the form most likely to be encountered in natural waters contaminated with plutonium and is the form suspected in nuclear processing waste streams. Sheidina and Koverskaya (1970) studied the colloidal state of Plutonium IV and noted a change in particle charge dependent upon concentration and pH. This result confirms the suggestion by Rhodes (1957a, 1957b) that radiocolloids are positively charged up to about pH 8 and negatively charged at higher pH's. The behavior of the cation, in part, would explain the soil sorption phenomenon. However, when Hajek (1966) leached plutonium contaminated sandy soil with water or 1 N NaNO_3 only 0.1% and 3.5%, respectively, of the plutonium was leachable. Movement was ascribed to solubility and not exchange mechanisms. Wilson and Cline (1963) used standard (agricultural) soil extraction procedures for studying the removal of plutonium IV from agricultural soils. Dilute ammonium acetate or nitric acid extractants removed less than 1% of the added plutonium. DTPA (diethylenetriaminepentaacetic acid) also removed less than 1% of the plutonium. These studies support the theory that solubility is more important than soil exchange mechanisms to the movement of plutonium in soil when plutonium bearing particles are not present. Christenson and Thomas (1962) noted extensive movement of plutonium waste through Los Alamos tuff but felt that liquid flow along fissures in the substrate was responsible although the possibility existed for organic complexes to be present. In an earlier report, Christenson et al. (1958) studied the movement of plutonium IV through soil cores and noted that the plutonium was tightly held in the soil and not leachable with 100 ppm solutions of sodium, calcium, or magnesium as well as a CO_2 saturated water. They pointed out, however, that because plutonium readily forms complexes which are difficult to remove from solution, such complexes would

not be expected to be retained by soils. Rhodes (1957a) demonstrated the mobility of plutonium in soil with extracting solutions using an equilibrium technique. Treatment with 5 successive extractions with 8 M ammonium acetate removed 98% of the plutonium. It was concluded that the extraction of plutonium was probably due to the formation of anionic acetate complexes and not the effect of the extracting cation. An oxalate plutonium complex also was noted to behave as an anion. Knoll (1969) recorded similar results with organic solvents which are used during nuclear fuel reprocessing operations. Plutonium was sorbed by soil from only one preparation, and the pretreatment of soil with organic solvents had no effect on the soil exchange capacity. Hydroxyacetic acid was effective in leaching plutonium from soil and its effect was directly proportional to acid concentration. Less than 10 column volumes of .25 M acid removed more than 50% of the plutonium.

The transuranic radioelements americium, cerium, and neptunium have received very little attention. Both Hajek and Knoll considered americium as well as plutonium in their studies. Hajek noted greater leachability of americium (7.5% with water and 33% with N NaNO_3) and interpreted leach rates as indicating soil exchange. Knoll reported that americium was twice as easily removed from soil by organic solvents than was plutonium, and up to 100% could be removed with hydroxyacetic acid. Wallace (1971) reported the extraction of americium from a loam soil by DTPA to be 100% effective. Preliminary results were obtained by Cline (1967) who studied americium-tagged acidic or basic soils. When soil columns were leached with 100 in. of irrigation water, americium movement through the basic soil (ca. 6 in.) was greater than through the acidic soil (ca. 1 in.). Thomas and Jacobs (1969) studied the behavior of curium in plants and soil. Formation of radiocolloid particles were believed to govern the behavior of curium in soil and similarities to plutonium were noted. However, precipitation from stock solutions occurred above pH 3. Ion exchange was not thought to be important in soil systems for curium. Reports on the behavior of neptunium in soils are unknown. Because of its potential hazard neptunium is routinely removed from processing wastes, but like

plutonium, some escapes scavenging and passes through the process.

Plants

Relatively few plant uptake studies have been conducted on alpha-emitting elements other than observations related to geobotanical prospecting where uptake was noted to be in the order radium > uranium > thorium.¹⁰¹ Short term studies have reported less than 10% uptake of neptunium, plutonium, americium, or curium which agrees with the predicted uptake of heavy metals.

Plutonium uptake by plants has been studied from fallout and other sources. Nishita et al. (1965) reported that ladino clover uptake of fallout plutonium in soil was very low ($CF = 0.0001$). Only trace amounts of alpha activity were detectable in tomato plants grown on fallout contaminated soil, and no uptake was recorded for bean, barley, or tumbleweed (Russian Thistle) (Selders et al. 1955). Jacobson and Overstreet² reported that plutonium uptake by barley from clay suspensions was greatest for valence state VI (PuO_2^{+2}) which agreed with its least sorption to the clay suspension and greatest sorption to root surfaces compared to the other valence states tested (III and IV). The sorption of plutonium IV to root surfaces from culture solutions was noted also by Rediske and Selders (1953) and Rediske et al.¹¹ and was linear with respect to concentration, whereas, leaf concentrations appeared to be curvilinear. The uptake into shoot tissue by tumbleweed from solution cultures was slightly less than for bean, barley or tomato. The CF value for barley from a Neubauer test was 0.0009 and considered an overestimate of the uptake which could be expected under field conditions.¹¹ Wilson and Cline⁸¹ compared the uptake of plutonium from soil by barley with that of tungsten and lead. Uptake of plutonium IV from an acid soil was greater than uptake from alkaline or calcareous soils, and plutonium uptake was less than tungsten or lead. Cline (1967) later reported the uptake of americium and plutonium from two of the same soils and indicated CF values of .003 for americium uptake from either soil and .0002 and .0001 for plutonium uptake from the acid and alkaline soil, respectively. Americium was noted to be toxic to pea

seedling roots when the culture concentration was 0.1 mCi/l; plutonium was not as toxic. Cline concluded that americium and plutonium behave in chemically different manners and the former cannot be used as a tracer for the latter.

There is some indication that plutonium uptake by plants may be enhanced with successive cropping and the passage of time. For instance Neubold and Mercer (1962) and Neubold (1963) reported that although plutonium uptake by perennial ryegrass was low, it did increase over the two year period of study. It was detectable in the third harvest of the first growing season for one of the three soils studied (an acid soil) and the fourth harvest showed barely detectable uptake from all three soils. Results from the next growing season indicated that uptake from the acid soil was nearly 4-fold greater than the previous years maximum. The experiment was reported as being continued, but further results have not been published. Romney et al.¹¹⁷ studied the uptake of fallout plutonium by clover over a period of 5 years. A 7-fold increase was noted in plutonium uptake into foliage tissue, under glasshouse conditions. It was postulated that the increase in uptake was due to either more perennial roots coming into contact with plutonium particles as the plants aged or that natural organic materials resulting from root tissue decay complexed with the plutonium and resulted in increased uptake. The influence of chelating agent on the uptake of plutonium was then studied because chelates enhance plant uptake of heavy metals, and it was thought that these kinds of organic compounds may naturally occur in soil. A DTPA chelate produced as much as a 20-fold increase in plutonium uptake by alfalfa grown on fallout contaminated soil. Hale and Wallace (1970) compared the effects of different chelating agents (DTPA, EDDHA and FeEDDHA) on the uptake of heavy metals from soil by bush beans. DTPA increased americium uptake by nearly a 1000-fold for 15-day old plants but the effect was greatly reduced for 31 and 45-day harvests. Wallace (1971) further studied DTPA and noted its ability to promote uptake of americium into soy beans. A 200-fold increase in uptake resulted when Fe-DTPA was applied to the soil. It was also noted that americium was readily translocated within the plant following initial uptake, e.g., from old leaves to newly formed leaves or to roots, but

DTPA had little effect on retranslocation. Freshly added DTPA also increased americium uptake by citrus from soils contaminated the previous year. Studies on the increased uptake of transuranic elements by chelating agents are important because of the commercial use of these agents as a means of supplying some micronutrients to crop plants. Inadvertent use of chelates in areas where contamination levels are high (e.g. radioactive waste disposal areas) could have far reaching effects.

Only one report each on the uptake of curium or neptunium by plants has been published. Thomas and Jacobs (1969) reported on the uptake of curium by beans and tall fescue from soil or solution cultures. One experiment involved the uptake of nutrient solution directly into the transpiration stream when roots were excised. The treatment resulted in an increased uptake of more than 2.5 times compared to intact bean plants. Unexpectedly, bean plant uptake from soil cultures was more than twice that from nutrient solution, however, the former amounted to only 0.068% of the dose. Uptake by grass was undetectable. It was concluded that curium radiocolloids could be translocated upward in the transpiration stream, and it was postulated that abrasion of roots by soil particles and greater activity by microorganisms might have afforded direct entry of the soil solution into the plant and resulted in greater shoot activity as compared to uptake from solution culture by intact plants. Davis et al. (1956) studied biological uptake of neptunium and fission elements from reactor effluent water. A nutrient culture technique using effluent water resulted in 0.13% of dose uptake of neptunium into bean plants after 14 days growth. However, 33% of dose was associated with roots.

Available data suggest the possible order of plant uptake from soils as curium > americium > plutonium with neptunium probably being closest to plutonium. This is consistent with the correlation of increased skeleton burden with decreasing ionic radius established by Durbin (1962). The greater uptake and predictable behavior expected of curium in soil-plant systems may be attributable to its single valence state. The other three elements (and uranium) predominately occur in one state, but three additional valence states are possible, and possible biological mechanisms permitting oxidation or reduction remain uninvestigated. The chemical toxicity of

plutonium to biological systems has been known for some time. Bair and Hungate (1956) provide evidence of plutonium IV toxicity to a plant system (yeast) and also noted a similarity to known effects of uranyl ions. The observation that americium is even more toxic than plutonium is in sharp contrast to its demonstrable greater uptake by plants. The relationship between toxicity and uptake as well as the influence of alpha radiation on plant membrane permeability need to be explored.

Animals

Transuranic elements in mammalian systems has been the principle topic of two major symposia.* The toxicity and behavior of these elements in laboratory animals is well understood in comparison to what is known about native animals. Internal health hazard has been studied extensively and inhalation is accepted as the principal mode of entry into the body. The serious nature of handling industrial quantities of plutonium has been realized for more than a decade (Langham, 1959).

Romney et al.¹¹⁷ recently reported some of the data from field surveys at NTS. High levels of plutonium were found in the gastrointestinal tracts of kangaroo rats and jackrabbits which indicated that ingestion, in addition to inhalation, was an important source of residual fallout plutonium to these wild animals. The assimilation of transuranic elements by animals from a natural source of food (either herbivores or predators) has not been studied in detail although it is widely recognized that ingestion is the most important transfer mechanism in ecosystems.

Paglia (1968) reported on hematopathologic surveys of kangaroo rats native to plutonium contaminated as well as noncontaminated regions at NTS. Statistically significant blood cell depression were noted in animals of some exposed groups but physiological significance remained to be demonstrated. Animals collected from the area with greatest Pu contamination ($720 \mu\text{gm}/\text{m}^2$) showed the highest body burden (GI tract, lungs and bone) and the greatest blood cell depressions. Collections were made up to two years post detonation. No evaluation of the degree of food contamination was attempted

* Hanford Symposium on the Biology of the Transuranium Elements, May, 1962, Richland, Washington. Proc. in Health Phys. 8(6): 561-780.
The Biological Implications of the Transuranium Elements, September, 1971. Richland, Washington. Proc. to be published in Health Physics.

and it was assumed that internal deposition resulted from either gastrointestinal or pulmonary intake. Nenot et al. (1971) recently discussed the comparative behavior of neptunium, plutonium, americium and curium in mammalian bone tissue. The behavior of these elements whether administered by intramuscular injection or by aerosol is very different, and like their behavior in soils and plants, valence dependent. Slight differences due to mass (Pu-238 vs Pu-239) also were noticed. DTPA was effective in therapeutic treatment of bone deposits of elements in valence states III and IV.

Only two studies are known to have been reported on insects. Davis et al. (1956) observed that caddis fly larvae in the Columbia River accumulated neptunium from reactor effluent. Concentration factors were 280 for water-algae and 32 for algae-caddis fly larvae. Erdman (1962) studied the effects of ingested plutonium (from a sugar solution) on life span and reproductive behavior of a wasp, (Habrobracon). Rather large doses (0.08 $\mu\text{Ci/mg}$ food) reduced egg production, and chromosomal damage was suspected.

Aquatic Habitats

A comprehensive and up-to-date appraisal of available data on plutonium and other transuranics in aquatic environments has been prepared by Noshkin (1971). Studies on ecological aspects concerning the dissemination of fallout plutonium in marine systems have been emphasized in past research studies. The few survey-type data available for freshwater systems indicate similarities to marine systems where sediments are the principle repository and sediment feeding organisms usually have high body burdens. There is some evidence that plutonium is concentrated in aquatic food webs as are other radioelements.

References Cited

- Andelman, J. B. and T. C. Rozzell. 1970. Plutonium in the water environment. In: Radionuclides in the Environment, R. F. Gould (ed.) pp. 118-137. Amer. Chem. Soc. (Publ.)
- Bair, W. J. and F. P. Hungate. 1956. Chemical toxicity of plutonium in yeast. USAEC Doc. HW-47500. pp. 195-200.
- Christenson, C. W., E. B. Fowler, G. L. Johnson, E. G. Rex, and F. A. Virgil. 1958. Soil adsorption of radioactive wastes at Los Alamos. Sewage and Ind. Wastes 30: 1478-1489.

- Christenson, C. W. and R. G. Thomas. 1962. Movement of plutonium through Los Alamos tuff. In: Ground Disposal of Radioactive Wastes. J. M. Morgan et al. (eds.) USAEC Doc. TID-7628, pp. 248-281.
- Cline, J. F. 1967. Uptake of ^{241}Am and ^{239}Pu by plants, USAEC Doc. BNWL-714. pp. 8.24-8.25.
- Davis, J. J., R. W. Perkins, R. F. Palmer, W. C. Hanson and J. F. Cline. 1956. Radioactive materials in aquatic and terrestrial organisms exposed to reactor effluent water. Proc. Intl. Conf. on Peaceful Uses of Atomic Energy, Geneva, 1955, 13: 423-428.
- de Bortoli, M. C. and P. Gaglione. 1969. Natural and fallout radioactivity in the soil. Health Physics 17: 701-710.
- Denham, D. H. 1969. Health physics considerations in processing transplutonium elements. Health Physics 16: 475-487.
- Durbin, P. W. 1962. Distribution of transuranic elements in mammals. Health Physics 3: 665-671.
- Erdman, H. E. 1962. Effects of ingested Pu^{239} on fecundity, fertility and life span of *Habrobracon* (Hymenoptera: Braconidae). Health Physics 8: 635-638.
- Hajek, B. F. 1966. Plutonium and americium mobility in soils. USAEC Doc. BNWL-CC-925. p. 9.
- Hale, V. Q. and A. Wallace. 1970. Effect of chelates on uptake of some heavy metal radionuclides from soil by bush beans. Soil Sci. 109: 262-263.
- Knoll, K. C. 1969. Reactions of organic wastes and soils. USAEC Doc. BNWL-860. p. 13.
- Krey, P. W., D. Bogen and E. French. 1962. Plutonium in man and his environment. Nature, Lond. 195: 262-265.
- Krey, P. W. and E. P. Hardy. 1970. Plutonium in soil around the Rocky Flats Plant. USAEC Doc. HASL-235. p. 44.
- Langham, W. H. 1959. Physiology and toxicology of plutonium-239 and its industrial medical control. Health Physics 2: 172-185.
- Langham, W. H., P. S. Harris, and T. L. Shipman. 1966. Plutonium dispersal by accidental or experimental low-order detonation of atomic weapons. USAEC Doc. La-1981 (Revised) p. 42.
- Langham, W. H. 1968. The problem of large-area plutonium contamination. Bureau of Radiological Health Seminar Paper 002. Doc. NP-18208. p. 15.

- McKay, H. A. C. 1961. Alpha emitters in reactor wastes. In: Atomic Energy Waste: Its Nature, Use and Disposal, E. Glueckauf (ed.), pp. 99-108. Interscience, New York.
- Mork, H. M. 1970. Redistribution of plutonium in the environs of the Nevada Test Site. USAEC Doc. UCLA 12-590.
- Menot, J. C., R. Masse, H. Morin and J. Lafuma. 1971. An experimental comparative study of the behavior of ^{237}Np , ^{238}Pu , ^{239}Pu , ^{241}Am and ^{242}Cm in bone. Presented at the Eleventh Hanford Biology Symposium, The Biological Implications of the Transuranium Elements, Sept. 1971, Richland, Washington.
- Neubold, P. 1963. Absorption of plutonium-239 by plants. Gt. Brit. Agric. Res. Council, ARCRL-10. p. 86
- Neubold, P. and E. R. Mercer. 1962. Absorption of plutonium-239 by plants. Gt. Brit. Agric. Council. ARCRL-8, pp. 81-82.
- Nisnita, H., E. M. Romney and K. H. Larson. 1965. Uptake of radioactive fission products by plants. In: Radioactive Fallout, Soils, Plants, Foods, Man. E. B. Fowler (ed.), Elsevier, New York, pp. 55-81.
- Noshkin, V. E. 1971. Ecological aspects of plutonium dissemination in aquatic environments. Presented at the Eleventh Hanford Biology Symposium, The Biological Implications of the Transuranium Elements, Sept. 1971, Hanford, Washington.
- Paglia, D. E., 1968. Hematopathologic surveys of kangaroo rats (Dipodomys microps) populating plutonium contaminated regions of the Nevada Test Site. Health Physics 15: 493-498.
- Prout, W. E. 1958. Adsorption of radioactive wastes by Savannah River Plant soil. Soil Sci. 86: 13-18.
- Rediske, J. H. and A. A. Selders. 1953. The absorption and translocation of Pu-239 and Ce-144. USAEC Doc. HW-30437. pp. 40-45.
- Rhodes, D. W. 1957a. Adsorption of plutonium by soil. Soil Sci. 84: 465.
- Rhodes, D. W. 1957b. The effect of pH on the uptake of radioactive isotopes from solution by a soil. Soil Sci. Soc. Proc. 21: 389-392.
- Romney, E. H. and J. J. Davis. 1971. Ecological aspects of plutonium dissemination in the environment. Presented at the Eleventh Hanford Biology Symposium, The Biological Implications of the Transuranium Elements. Sept. 1971, Richland, Washington.
- Selders, A. A., J. F. Cline and J. H. Rediske. 1955. The absorption and translocation by plants of radioactive elements from "Jangle" soil. USAEC Doc. HW-27620. p. 13.

- Sheidina, L. D. and R. N. Koverskaya. 1970. Colloidal state of Pu IV in aqueous solutions. Translated from Radiokhimiya 12(2): 253-259. Original article June 2, 1969.
- Thomas, W. A. and D. G. Jacobs. 1969. Curium behavior in plants and soil. Soil Sci. 108: 305-307.
- Thompson, R. C. 1967. Biological Factors. In: Wick, O. J. (ed.). Plutonium Handbook: A guide to technology. Gordon and Breach, New York, N.Y. pp. 785-829.
- Wallace, A. 1971. Increased uptake of ^{241}Am by plants caused by the chelating agent DTPA. Presented at the Eleventh Hanford Biology Symposium, The Biological Implications of the Transuranium Elements, Sept. 1971, Richland, Washington.
- Wilson, D. O. and J. F. Cline. 1963. Removal of Pu^{239} , W^{185} , and Pb^{210} from soil by plants and ion extracting solutions. USAEC Doc. HW-80500, pp. 187-190.
- See also main bibliography entry No's. 2, 11, 58, 81, 101, 117.

APPLICATION OF RESULTS TO THE HANFORD SITUATION

The majority of data on the biological uptake of radionuclides fall short of direct application to waste management at Hanford. One reason is the lack of field studies conducted in arid climates and particularly in the presence of small ponds. The prediction of bioenvironmental consequences of radionuclide disposal under any set of conditions is difficult. Adding a special attraction, like a small pond, to an area compounds the problem. Prediction difficulties result from a wide range in biological variability, large numbers of environmental combinations with each likely to produce its own effect, and insufficient information on fundamental relationships between organisms and their environment. It is no wonder that regression analyses looking for correlations between organisms and their environment usually show poor results unless very carefully controlled conditions are maintained. Waste management practices should draw on general ecological principles, but the specific environmental and biological conditions of the site always must be identified. Recommendations necessarily will be based in part on empirical considerations.

Table 2 is a summary of concentration factors reported in the literature and is informative despite its shortcomings. The summary does not include

Table 2. Relative ranges of concentration factors (CF) for selected radioelements expressed as $\log_{10}$ exponents. Aquatic habitat CF values are relative to water; terrestrial CF values are relative to plants except where noted.

	<u>-4 to -3</u>	<u>-3 to -2</u>	<u>-2 to -1</u>	<u>-1 to 0</u>	<u>0 to 1</u>	<u>1 to 2</u>	<u>2 to 3</u>	<u>3 to 4</u>	<u>4 to 5</u>
<u>Aquatic habitats</u>									
Unicellular algae and Diatoms						Sr,Cs	Sr,Cs,Co	Sr,Cs,Ru Zr	Sr
Filamentous algae							Sr,Cs,Ce Zr	Sr,Co,Ce Zr,Cs	Zr
Submerged vascular plants						Co	Sr,Ru,Cs Co	Sr,Cs,Ru Co	
Emergent vascular plants				Cs	Cs	Sr,Cs	Sr,Cs,Co		
Invertebrates spp.						Ru,Zr	Sr,Cs,Ce Zr	Sr	
Insects				Cs,Ru,Co	Cs,Ru,Co	Cs,Ru	Cs,Ru	Ru	
Crayfish and snail flesh							Sr,Ru	Cs	
exoskeleton							Co,Ru	Co	Sr,Cs
Molluscs - flesh							Sr,Cs,Co Ce		
- shell						Cs	Sr,Co	Sr	Sr
Vertebrate spp.						Co	Sr,Co	Cs	
Fish - flesh					Sr,Cs	Sr,Cs,Co	Cs	Cs	Cs
- bone						Sr,Cs	Sr,Cs	Sr	
Waterfowl - flesh								Cs	
- bone							Sr		
Bottom Sediments							Sr,Co	Ce,Zr	Cs
<u>Terrestrial habitats</u>									
Invertebrates				Sr,Cs,Ru	Ru				
Small mammals				Co,Sr,Cs,Ru	Sr,Cs				
Vascular plants (based on soil)	Pu	Ru,Co,Sb Zr,Pm	Cs,Ru,Co,Sb Ce,Zr	Sr,Cs,Ru,Co Ce,Zr	Sr,Ru,Ce	Sr			

all studies conducted because frequently concentration factors were not calculated. However, consideration of the range of reported values tends to overcome this fault. The calcium status of the substrate influences the uptake of strontium which undoubtedly is reflected in the large variation of concentration factors reported. Values greater than 1.0 (i.e. $\log_{10} CF$ where $CF = 0$) represent accumulation relative to water (for aquatic habitats) or plants (terrestrial habitats). It is evident that the mobility of radionuclides in aquatic systems is far greater than in terrestrial systems although the bases used for comparison are different (water vs plant). Additional terrestrial studies* have reported fallout cesium concentration factors for herbivores (including man) of 2 to 3, and 8 to 9 for large mammal predators. It is clear that conversion from an aquatic to a terrestrial habitat would reduce biotic uptake and food web turnover by several orders of magnitude. Moreover, a change of this type would reduce the attractiveness of an area and result in fewer numbers of inhabitant species.

I. Aquatic habitats:

The most important waste management procedure of bioenvironmental significance practiced at Hanford is the routing of low-level liquid wastes (<50 pCi/ml) into open ponds. The procedure has been practiced at all major nuclear installations as a practical means of disposing of very large volumes of water. However, radionuclides (except tritium and probably ruthenium) are concentrated in the process and accumulate in the biota and pond sediments, and further concentration can be expected along food web pathways. If the pond is allowed to drain dry, materials are then available for uptake into a terrestrial system. Studies on White Oak Lake bed indicate the availability of radionuclides from such sources but it is generally less than from aquatic habitats. There is evidence to predict that the most plausible short term transport of radionuclides from ponds to man is via waterfowl, but deer might also be important. The spread of contamination due to blowing tumbleweeds and other vegetation as well as animal transport

* Cited in reference No. 116.

away from the ponds is an important nuisance factor to consider. The best maintenance techniques for existing situations would be those which restrict the movement of radioactive materials into the biota. An inventory of radionuclides released into the environment should be maintained and the ultimate fate of each important radionuclide determined. An inventory of Hanford waste is kept*, although release estimates are derived from building operations and not from material known to be carried into the ponds. Very little is known of the ecological fate of radionuclides in the waste ponds.

A good way to restrict biotic uptake and turnover through food webs is to maintain the simplest ecosystem practicable. In most cases this can be accomplished by restricting species. For example, the ponds are closed artificial systems and have no natural fish populations. They should be maintained in that manner so as not to attract wildlife which utilize fish as a source of food. There is ample evidence indicating that fish accumulate strontium, cesium and cobalt from both food and water. Further transfer through a food web can be efficient.

Waterfowl might represent a problem under present conditions. Relatively large numbers of migratory and resident waterfowl utilize the ponds and undoubtedly have varying body burdens of strontium, cesium and perhaps other radionuclides. Evidence from the literature indicates that edible ducks can accumulate cesium into their flesh 2000 times the concentration of cesium in the water of their habitat. Several methods tried in the past to discourage waterfowl usage of Hanford ponds resulted in various degrees of success. The relatively short period (perhaps a week or two) that an individual migratory waterfowl may use the ponds is a saving feature, but the problem should be thoroughly investigated and rectified even if it is necessary to restrict access to pond surfaces.

It is known from ecological studies that the number of species inhabiting an area normally increases as community succession advances. Some ponds are in advanced stages of community succession and represent a

* See: R. W. Harvey and H. T. Karagianes. 1970. Hanford Waste Management Plans. USAEC Document CPD-220 Rev. 1.

poor management choice because of the large numbers of animals which are attracted to food, shelter, and water. Natural vegetation around most of the ponds has been replaced by a kind of riparian community rich in weedy species, but nevertheless attractive to various animals such as insects, hawks, owls, mice, muskrats, rabbits, coyotes, raccoons, badgers, and deer. The smaller mammals probably do not wander more than 2 miles from the pond sites, but medium sized mammals (e.g. jackrabbits and coyotes) may travel 5 to 8 miles. Tagged Hanford deer (along the Columbia River) are known to roam more than 20 miles. Body burdens of pond resident deer have not been studied nor have their migratory habits and possible interaction with Columbia River herds. Both matters should be examined. Control measures required to discourage vegetation succession also should be a subject for research. A type of biological control should be developed whereby a simple, early succession stage plant community is established and maintained. The development of large cottonwood and willow trees would not be allowed because of their attractiveness to wildlife.

II. Terrestrial habitats:

When the use of a pond is discontinued, the basin should be backfilled but not until the sediments are mixed into the soil beneath the surface. Rooting volume is an important factor, and an increase in the volume of contaminated soil usually results in an increase in plant uptake when radionuclide concentrations are held constant. However, studies comparing plant uptake from a thin band of contaminated soil to the same amount of radionuclide spread throughout a large volume of soil showed greater uptake from the banded source. Studies also have demonstrated that plant uptake from surface applications can exceed uptake from soil mixtures because most root development occurs near the soil surface. Rooting characteristics vary from species to species. However, it is suspected in arid climates that the maximum penetration of yearly precipitation limits the depth of root development for annuals. Thus, sound procedures in decommissioning ponds are to (1) mix bottom sediments with soil by discing or plowing, (2) backfill with 3-4 ft. soil, (3) add 1-2 ft. top-soil or fine grained soil, and

(4) plant a cover crop to stabilize the soil surface. The best cover crops are annual grasses which reseed themselves each year and characteristically have shallow root systems. Annuals must develop a new root system each year, hence, their roots are less likely to reach a buried source of contamination compared to perennial species. Winter annuals tend to deplete soil moisture to levels below those required to establish undesirable, deep rooted summer annuals. A local species would be the best choice so as not to create an unusual habitat and attract wildlife to the area. Irrigation should be used only to establish the cover crop. Water penetration should not be permitted to reach the contaminated zone. Irrigation would not be necessary beyond the first year.

III. Recommended studies:

As information is gained on long-term movement of environmental pollutants, it is increasingly important that ecological standards be maintained for all waste disposal practices concerning the biosphere. As waste disposal sites age, short-lived radionuclides decay and long-lived materials become increasingly important. All fission and decay products, as well as activation products, with half-lives greater than three years should be considered as potentially important due to their presence in ecosystems for more than twenty years.

The following priority listing of research topics is suggested from literature evaluation and information on current low level waste management practices at Hanford. The accumulation of information from studies within these topics will result in establishing concentration factors for major members of local ecosystems. These, together with the identification of food web pathways, will serve to establish transient times and important intermediate stages. The general objective of the studies, however, is to identify the ecological fate, i.e., the ultimate biological or environmental sink, of each important radionuclide under long term natural conditions. If the natural fate is unacceptable, then management practices must be developed to create a condition which is acceptable.

Research Topics

1. Determination of radionuclides present in the environs.

A complete environmental inventory should be made of the current location of all detectable radionuclides present in the Hanford environs. Detailed sampling should be done in accord with recognized ecological categories in order to be of greatest value.

2. Detailed examination of routine environmental surveillance data.

Most of the existing radiological survey data are not expected to be useful in evaluating the ecological fate of radionuclides at waste disposal sites; however, a review of their usefulness should be undertaken.

3. Alpha emitting radionuclides in the environment.

Very little information is available on the biological or environmental (i.e. ecological) behavior of neptunium, plutonium, americium or curium. The environmental inventory may eventually suggest areas of accumulation, but the basic ecological behavior of these elements also should be examined. Studies especially relevant are those concerned with (1) the effects of time on biological availability, (2) the significance of possible chelation or organic complexing by natural products of growth or decay, (3) selective uptake and accumulation by local biota, and (4) the efficacy of natural biological transfers.

4. Radioecology of unusual radionuclides characteristic of low level waste disposal areas.

Very long lived radionuclides such as technetium, and perhaps others identified from the environmental inventory, will increase in importance as shorter lived radionuclides decay. There apparently is no information on the behavior technetium in soils, on plant uptake, or on food web transfers although the shorter lived isotopes are used as medical tracers. The behavior of cobalt in arid land ecosystems is mostly unknown.

5. Control of long standing nuisance factors.

Two biological vectors of radionuclides have been long recognized as important nuisances to low level waste management, i.e., tumbleweeds

and waterfowl. Vegetation cover is necessary for wind erosion control, and studies should be conducted to determine the best type for that purpose which does not create additional problems. The effectiveness of restricting waterfowl use of ponds by vegetation control and camouflage should be investigated.

6. Radionuclide availability from special substrates.

There are two sources of radionuclides available to the biota unique to Hanford. First, it may not always be practical to control every tumbleweed which has accumulated strontium. The biotic availability of strontium (oxalate) from tumbleweeds and perhaps pond weed should be determined. Second, there are several situations where fresh or decaying sediments provide a source of radionuclides to the biota. Radionuclide release and availability characteristics from such sources are unknown. Food web transfers from a sediment base should be determined.

7. Animal transport of radionuclides away from disposal areas.

The potential transport of radionuclides of greatest local importance concerns deer which reside near disposal ponds. Their body burdens and movements away from the areas should be determined. Smaller mammals, birds (owls, swallows) and insects may not be important but these factors should be determined.

8. Validation of early biological uptake data for Hanford.

The results of some early work at Hanford conflict with those of recent studies. The biological availability of cesium (primarily plant uptake from local soils) should be investigated especially in light of current interpretations that the availability of cesium may increase with time under conditions of chronic contamination.

9. Elucidation of local food webs.

Observation on food web transfers normally would be made during all field studies. It is not necessary to quantify transfers for purposes of management because concentration factors are used to indicate the integrated result of transfers. Where food web pathways are not determined incidentally, a special effort must be made.

SUMMARY AND CONCLUSIONS

Data available in the literature indicate the relative ease with which radionuclides circulate through ecosystems in accord with biogeochemical processes. Because waste radionuclides characteristically are initially present in low concentrations and may consist of or be mixed with toxic chemicals are of little consequence. The ability of individual organisms to concentrate radionuclides either internally or externally and the passage of these concentrated sources through food webs, frequently with additional concentration, are typical features of natural ecosystems. It is evident that water has a large solubilizing effect on the availability of radionuclides resulting in an increase in biological uptake and concentration which distinguishes aquatic systems from terrestrial system. Aquatic systems are further characterized by radionuclide concentrations resulting from physical phenomena such as precipitation, flocculation and adsorption. Bottom sediments are the combined effect of physical and biological processes and frequently represent significant sources of contamination. Aquatic systems have been studied much more extensively than terrestrial systems but the importance of radionuclide transfers in terrestrial systems should not be minimized. The interactions of physical, chemical and biological parameters make it extremely difficult to predict specific consequences of radionuclides in the environment. Waste management practices should draw on general ecological principles, but the specific environmental and biological conditions of the site always must be identified. Recommendations necessarily will be based in part on empirical considerations.

In addition to research topics unique to the Hanford situation, it would be desirable to have a better understanding of the environmental behavior and distribution of the transuranic elements neptunium, plutonium, americium and curium. Moreover, the fate of cobalt in the environment is poorly understood, and that of technetium is unknown. There is evidence that processes acting through time increase the availability of long lived radionuclides. Ultimately, the very long lived radionuclides will be of greatest importance to man and his environment.

ANNOTATED BIBLIOGRAPHY

The following list of references contains the material considered in this report except those additional sources given for the special section on transuranic elements (see page 26). The numbered list is arranged chronologically and alphabetically within years. Abstracts contain information relevant to this report and may not include all information given in the paper. Statements in lieu of complete sentences are sometimes used for the sake of brevity.

1943

1. Robinson, W. O. 1943. The occurrence of rare earths in plants and soils. Soil Sci. 56: 1-6.

Some plants (e.g. Hickory) have affinity for rare earths, but mechanisms not understood. Postulated that plants capable of producing oxalates and oxalic acid probably will be accumulators of rare earths because, like Ca, of the insolubility of RE oxalates and crystal formation that results. Y, Ce, Pr, Sm are greatest accumulators by Hickory leaves. Noted that old leaves accumulate most; some plants accumulate very little.

1948

2. Jacobson, L. and R. Overstreet. 1948. The uptake by plants of plutonium and some products of nuclear fission adsorbed on soil colloids. Soil Sci. 65: 129-134.

First published report on uptake of fission products and Pu by plants. Uptake was from clay suspensions (short term) or soil (long term) by barley and pea, resp. Concluded that plants do take up elements Sr, Y, Ce, Zr, Nb, Te, and 3 valence states of Pu:

$\text{PuO}_2^{+2} > \text{Pu}^{+4} > \text{Pu}^{+3}$ from suspension and soil. Relatively large amounts of all nuclides were associated with roots (10-30% dose).

1950

3. Selders, A. A. 1950. The absorption and translocation of fission elements by Russian thistle. HW-18034 (Declassified).

Results of very early study on uptake of fission products by tumbleweed from a waste line leak. Determined amount of β -activity taken up, distribution in plant, and gross effects on morphology. Activity was not absorbed by native plants until the 3rd month of growth (because FP between 3rd and 4th foot below surface). Most activity appeared to be Sr-Y and located in particles within plant parts, i.e. crystals at nodes. Radionuclide uptake into shoots: 90% Sr (Y); 5% rare earths; 1% Cs or Zr (Hb); <1% Ce (Pr) or Ru (Rh).

4. Vlamis, J. and G. A. Pearson. 1950. Absorption of radioactive zirconium and niobium by plant roots from soils and its theoretical significance. Sci. 111: 112-113.

Report of a very early study on plant uptake of Zr-Nb. Data on carrot top activity from plants grown on contaminated soil indicate Zr-Nb readily taken up. However, authors previously describe treating oxalate-⁹⁵Zr-Nb complex with H₂SO₄ and H₂O₂ before adding to soil to study release upon leaching with various organic and inorganic acids. Not stated whether this treatment carried out in plant uptake study. Oxalic and citric acids most effective in leaching from soil. Assume a complex is formed and leached from soil. Postulated that organic acid complexes (from root exudation and microorganisms) enhance plant uptake of elements like Zr-Nb.

1951

5. Selders, A. A. and J. W. Porter. 1951. The absorption and translocation of fission elements by Russian Thistle and alfalfa plants. HW-20231 (Declassified).

A brief follow-up to previous report on Russian thistle uptake from break in waste line. (K-3 Danger Zone, 200E). The location of new radioactive plants indicated new break in line. Alfalfa plants (4) transplanted to area also. Alfalfa became radioactive, but much less than thistle. May be due to slower root growth or lower absorption and translocation by alfalfa compared to thistle.

1953

6. Hill, C. A., S. J. Toth and F. E. Bear. 1953. Cobalt status of New Jersey soils and forage plants and factors affecting the cobalt content of plants. Soil Sci. 76: 273-284.

Study on Co uptake by plants in relation to animal nutrition. Surveyed many local soils and plants (forage, vegetables, weeds) - Co content of weedy spp. varied; Polygonum pennsylvanicum (smartweed) 31 ppm and Panicum capillare (panic grass) 15 ppm were high and intermed. resp. for group surveyed. Legumes were generally higher in Co than other plants (now known Co essential to symbiotic bacteria in root nodules, cf. Wilson, D. O. and H. H. Reisenauer, Plant & Soil 19: 364-373, 1963).

7. Rediske, J. H. and A. A. Selders. 1953. The uptake and translocation of cesium by plants. HW-35174.

Lab and greenhouse study on uptake of Cs by beans, wheat, barley and Russian thistle. Plants grown for 32 days. Uptake and redistribution: all plants showed uptake from solution culture and distribution throughout plant was about equal, but Cs is redistributed from older tissue poorly. Lowest uptake was by Wheat and Russian Thistle, Concentration

effect: uptake was proportional to concentration in nutrient solution. Russian thistle showed high degree of adsorption to roots.

8. Rediske, J. H. and A. A. Selders. 1953. The absorption and translocation of strontium by plants. *Plant Physiol.* 28: 594-605.

Study indicated that Sr readily taken up by plant but not redistributed within the plant. Uptake was proportional to concentration up to 100 ppm Sr^{++} for solution culture and Neubauer techniques. Accumulation in root decreased as pH of solution was decreased. Leaf-root ratio proposed as means of expressing uptake efficiency to overcome root sorption phenomenon. Barley leaf tissue CF = 1.4 (based on Sr added); 1.7% uptake of dose; Neubauer technique.

1954

9. Menzel, R. G. 1954. Competitive uptake by plants of potassium, rubidium, cesium, and calcium, strontium, barium from soils. *Soil Sci.* 77: 419-425.

Original paper by author suggesting use of OR (D.F. also) in describing relationships between Sr and Ca.

$$\frac{\text{Sr plant}}{\text{Ca plant}} = k \frac{\text{avail Sr soil}}{\text{avail Ca soil}} \quad \text{similar for Cs/K \& Rb/K}$$

k is "Distribution Factor" an index of similarity in behavior of element pair. Expect k to = 1 if no discrimination against uptake or translocation of either element if <1 Sr discriminated against relative to Ca. Most OR determined here were less than 0.5.

1955

10. Fuller, W. H., and W. J. Flocker. 1955. The uptake of radiostrontium by certain type crops from calcareous soils. *Ariz. Agric. Expt. Sta. Tech. Bull.* 130.

Several aspects of Sr uptake studied; one of interest here is crop plant uptake from crop residues containing radiostrontium. Uptake was greatest from residue having greatest amount of Sr and least from residue with least. Uptake also directly proportional to amount of residue present. (this pot expt. indicated Sr uptake to be less than 2% of total added as crop residue, field conditions would be expected to lower this amount). The amt. of Sr taken up from residues varied inversely with exch. Ca content of soil. Concluded that probably there is no difference in uptake from top or root residue by crop plants.

11. Rediske, J. H., J. F. Cline and A. A. Selders. 1955. The absorption of fission products by plants. HW-36734.

Used barley and the Neubauer technique. Results reported as CF for 9 local soils and compared with data for 4 soils reported by other workers (UCLA). Noted all elements slightly less available when pH increased. Concluded Sr most important F.P.; Cs important in some soils. Difference in spp and plant organ noted: Species - Russian thistle lower in uptake from solution culture compared to agricultural plants. FP were very much available for plant uptake from circumneutral sandy soils with low OM content and low exch. capacities. ^{239}Pu uptake reported for one soil -- very low. No details given but presumably was $\text{Pu}(\text{NO}_3)_4$.

1956

12. Klechkovsky, V. M. 1956. On the behavior of radioactive fission products in soil, their absorption by plants and their accumulation in crops. Part 2: The absorption of fission products by agricultural plants and their accumulation in crops. Academy of Sciences of the USSR, Moscow. AEC-TR-2867. 1957. USAEC Washington, D. C.

Work reportedly done independently of western scientists and largely agrees with west. Consistently noted Sr and Cs uptake primarily into shoot tissue of wheat, whereas, Ru, Ce, and Zr tended to stay in roots. Uptake from soil considerably less than from solution culture; especially Cs where three orders of magnitude difference noted. No data on soil Ca but soils 30% base saturated. Considerable amounts of radionuclides taken up without observable damage to plant (wheat). Many factors affect uptake, e.g.: soil organic matter; soil-colloid content; addition of lime, humus, and fertilizers. Species differences also observed and legumes generally had greater capacity to take up radionuclides than did cereal crops. CF's not given but can be calculated based on amounts added.

13. Krumholz, L. A. 1956. Observations on the fish population of a lake contaminated by radioactive wastes. Bull. Amer. Mus. of Nat. History 110: 281-367.

Report of very extensive study (1951-53) of fish in White Oak Lake, ORNL before it was drained in 1955. Many fish present, but two studied most for radiochemistry: bluegill and black crappie. Radionuclides found in fish: ^{89}Sr and ^{90}Sr , ^{90}Y , ^{137}Cs , $^{144}\text{Ce-Pr}$, and other rare earths. ^{106}Ru , ^{60}Co , ^{32}P , ^{131}I , $^{95}\text{Zn-Ilb}$. Hard tissues concentrated Sr and P (Sr 20000-30000 times water). A typical black crappie, had $>1\mu\text{c}$ (90% was $^{90}\text{Sr-Y}$). During winter levels were about 1/3. Similar data for bluegill. Soft tissues mostly contained ^{137}Cs (75%) and Ru (greatest conc. was 10% total). All others <3%.

14. Nishita, H., B. W. Kowalewsky, and K. H. Larson. 1956. Influence of soil organic matter on mineral uptake by tomato plants. Soil Sci. 32: 401-407.

An auxillary expt. described was to note differences between tagged and nontagged OM added to soil and subsequent uptake by tomato. No significant differences were noted in uptake by tomato from tagged OM added to

soil or OM added to tagged soil; no difference noted in type of OM added either (Lettuce or Barley), however, when straw added (increased C/N soil) plant growth and uptake of Sr^{90} were decreased at high levels of application. Other sources of OM had their own effect on mineral uptake due to differences in composition of OM material added.

1957

15. Bidwell, K. W. E. and E. E. Foreman. 1957. Distribution of Strontium-90 in pond weed and fish. *Nature* 180: 1195-1196.

Report briefly describes early qualitative work on strontium-90 uptake. CF (wet wt) for pond weed (*Myriophyllum*) was 270. Strontium was accumulated in nodal region and autoradiographs showed this to be in form of crystals (probably oxylate) agrees with other work on sugar beet. Concentration in plant relatively constant over 272 day period of study.

16. Krumholz, L. A. and R. F. Foster. 1957. Accumulation and retention of radioactivity from fission products and other radiomaterials by freshwater organisms. In: Revelle, R. (ed.). 1957. The effects of atomic radiation on oceanography and fisheries. Nat. Acad. Sci., Nat. Res. Council, Washington, D. C. Public. 551.

Paper generalizes with data available at time (1955) for Columbia River and White Oak Lake organisms. White Oak Lake was later drained. Noted that input to White Oak Lake contained Sr-Y, Cs, Ce-Pr, Ru and other fission products but most organisms utilized only a few elements. Also noted species variability, and position variability with respect to influent. Recognized 3 modes of uptake--1. adsorption to surface, 2. absorption from surrounding medium, and 3. through food chain.

17. Romney, E. M., J. W. Neel, H. Nishita, J. H. Olafson and K. H. Larson. 1957. Plant uptake of Sr^{90} , Y^{90} , Ru^{106} , Cs^{137} , and Ce^{144} from soils. *Soil Sci.* 83: 369-376.

Soil pot experiments to evaluate the capacity for barley, bean, carrot, lettuce, and radish plants to take up Sr^{90} , Y^{91} , Ru^{106} , Cs^{137} , and Ce^{144} from soils under greenhouse conditions. Results show virtually no Y^{91} , Ru^{106} , Cs^{137} , or Ce^{144} was taken up by these plants. Sr^{90} was readily taken up and was concentrated in greatest amounts in leaf tissue. The highest Sr^{90} levels were found in plants grown on acidic soils low in calcium and lowest levels on the alkaline-calcareous soils.

1958

18. Auerbach, S. E. and D. A. Crossley, Jr. 1958. Strontium-90 and cesium-137 uptake by vegetation under natural conditions. In: Proc. of the Sec. U. N. Intl. Conf. on the Peaceful uses of Atomic Energy, Geneva. 1958, Vol. 18: 494-499. U. N., New York.

Paper reports on revegetation studies (2 yrs) on White Oak Lake bed after draining. Concluded that different plants and different parts of same plant accumulate various proportions of strontium and cesium even when grown under same conditions of climate and soil. Data reported as $\mu\text{Ci}/100\text{gm}$ tissue.

19. Davis, J. J. and R. F. Foster. 1958. Bioaccumulation of radio-isotopes through aquatic food chains. *Ecol.* 39: 530-535.

Early study on Columbia River with P-32 and algae-caddis fly-minnow food chain and trophic level P was 150 ppm, 2000 ppm and 6000 ppm resp. However, uptake, turnover time, longevity at each trophic level and accumulation all depend on many biotic and environmental factors. Absorption and adsorption processes important to plants, whereas, uptake thru food chain most important to animals.

20. Fredriksson, et al. 1958. Studies on soil-plant-animal interrelationships with respect to fission products. In: *Proc. sec. U. N. Intl. Conf. on the Peaceful Uses of Atomic Energy, Geneva. 1958, Vol. 18: 449-470. U. N., New York.*

Data presented from this extensive study amply illustrate the reducing effect of soil calcium on plant uptake of strontium. Data for cesium show an increase in cesium uptake when carrier cesium is increased, hence, soils with illitic clays have strong but limited ability to hold Cs. Where Cs is continuously supplied and binding sites become occupied, Cs may become more available for plant uptake.

21. Graham, E. R. 1958. Uptake of waste Sr-90 and Cs-137 by soil and vegetation. *Soil Sci.* 86: 91-97.

Early studies on White Oak Lake bed are described as uptake of Sr-90 and Cs-137 by Polygonum lapathifolium (smartweed) an early plant colonizer. Data clearly show ability of plant to concentrate in its tissues Sr and Cs which is present in soil solution and freely available for uptake. Compared plant uptake based on soil "saturation extract" and total present in soil.

22. Gulyakin, I. V. and E. V. Yudintseva. 1958. Uptake of strontium, cesium and some other fission products by plants and their accumulation in crops. In: *Proceedings of the Sec. U. N. Intl. Conf. on the Peaceful Uses of Atomic Energy, Geneva. 1958. Vol. 18: 476-485. U. N., New York.*

Authors point out there is large difference between uptake by plants grown in solution culture and uptake from soil. Also, large differences may occur for distribution of radionuclides in plant body, i.e. leaves, stems, fruit, roots, etc. In general shoots tend to accumulate relatively more radionuclides than do roots. Uptake data (% of total uptake) are given for roots and shoots of Pea and Wheat grown in

solution culture with ^{90}Sr , ^{137}Cs , ^{106}Ru , ^{144}Ce , ^{91}Y , ^{95}Zr , ^{95}Nb but no data on amounts of uptake or CF values except Sr and Cs.

23. Kornberg, H. A. 1958. Radiation biology as a supporting function for atomic energy installations. In: Proc. of the Sec. U. N. Intl. Conf. on the Peaceful Uses of Atomic Energy, Geneva. 1958. Vol. 18: 329-335. United Nations, New York.

Paper describes efforts of Biology Operation, Hanford, up to 1957. Notable that: "Potential hazards of atomic energy production fall into two broad categories: hazards to man and hazards to forms of life in his environment." Observations of environmental monitoring program led to lab experiments on validity of MPC values, concentration factors for plants, and biological (animal) effects.

24. Nishita, H., A. J. Steen and K. H. Larson. 1958. Release of Sr-90 and Cs-137 from Vina loam upon prolonged cropping. Soil Sci. 86: 195-201.

Experiments were conducted to study the uptake of Sr-90, stable Sr, Ca, Cs-137, and K by Ladino clover as a function of extensive and prolonged cropping of a contaminated soil using the pot culture method. The exchangeable Ca, stable Sr, and Sr-90 decreased with time of cropping, but the concentrations of the cations per unit weight of dry clover remained, in general, fairly constant among all harvests. The K uptake by clover decreased as the exchangeable K in the soil decreased. As the K uptake by the plants decreased the uptake of Cs-137 increased. The fixation of Cs-137 in the soil appeared to have increased as non-exchangeable K was decreased by cropping. Maximum cumulative total percentages of Sr-90 and Cs-137 removed by 9 crops obtained over the period of 516 days were 23.69 and 0.72, respectively.

25. Pendleton, R. C. 1958. Effects of some environmental factors on bioaccumulation of cesium-137 in an aquatic community. Biology Ann. Rept. 1958. HW-59500. P. 42-46.

Second year results from small (30 ft diameter) concrete pond, cesium-137 concentrations in filamentous algae (Rhizoclonium and Spirogyra) were highest when water temperature was not inhibitory to growth (<6-8C, >25C). Shade induced by floating rafts of algae reduced Cs uptake by Elodea, Ceratophyllum and Potamogeton (submerged aquatics) by as much as 2/3. Cold winter temperatures also reduced Elodea uptake by > 1/2. Results also indicate that aquatic emergent species (Typha, Scirpus) take up considerable amounts of Cs directly from the water. Uptake for these plants was greater when planted in gravel than mud. Higher CF were noted in higher trophic level organisms because of presumed increased efficiency of retention by these animals (predators).

26. Pendleton, R. C. and W. C. Hanson. 1958. Absorption of cesium-137 by components of an aquatic community. In: Proc. of Sec. U. N. Intl. Conf. on the Peaceful Uses of Atomic Energy, Geneva. 1958. Vol. 18: 419-422. United Nations, New York.

Paper describes observations on effluent swamp (Redox) and an experimental pond. Concentration in swamp of cesium-137 ranged 1×10^{-7} to 6×10^{-6} $\mu\text{C}/\text{ml}$ water; pond contaminated at 6×10^{-3} $\mu\text{C}/\text{ml}$. Data show cesium-137 to accumulate and increase with increasing trophic level. Concentration factors for field study (swamp):

Rhizoclonium (algae): 1200
 Scirpus acutes (bullrush): seeds 70
 Polygonum lapathifolium (pale persicaria): seeds 240
 Fulica a. americana (coot): muscle 1800, liver 2200, bone 800
 Anas platyrhynchos L. (mallard): muscle 2000, liver 2500, bone 700
 Oxyura jamaicensis rubida (Ruddy duck); muscle 2200, liver 2800, bone 900

27. Williams, L. G. and H. D. Swanson. 1958. Concentration of cesium-137 by algae. Sci. 127: 187-188.

Unalgal cultures of nine native spp. (Oak Ridge vicinity) were studied and CF (wet wt basis) determined. Euglena and Chlorella cultures also studied for their "power" to decontaminate the medium of cesium-137. Cf varied from 52 to 1530. Biodecontamination improved with time 69% in 11 days to 96% in 34 days for Euglena. No difference between 1, 5, 10 $\mu\text{Ci}/\text{l}$ concentration. K and stable Cs both depressed cesium-137 uptake. Dead Euglena and Chlorella had CF of 16 and 418, resp. The latter is greater than living cells. Concluded that in living systems Cs and K form a metabolic pool whereas in dead system the two ions behave independently.

1959

28. Romney, E. H., G. V. Alexander, W. A. Rhoads, and K. H. Larson. 1959. Influence of calcium on plant uptake of Sr-90 and stable strontium. Soil Sci. 87: 160-165.

Additions of Ca reduced Sr-90 and Sr uptake by beans from nutrient solutions. Added CaCO_3 and CaSO_4 reduced Sr-90 or Sr uptake from a neutral, highly fertile sandy loam or from an alkaline-calcareous sandy loam.

29. Schulz, R. K., J. P. Hoberg, and R. Overstreet. 1959. Some experiments on the decontamination of soils containing strontium 90. Hilgardia 28: 457-475.

One of the experiments described was on the influence of soil placement depth, either with or without irrigation, on uptake of strontium 90 by barley under field conditions (lysimeters). Treatment depths were 2 in., 1 ft., 2 ft., 3 ft., and 4 ft. Rate of root growth was similar for both water regimes at 2 in. per day. $\mu\text{Ci}/\text{gm}$ were higher for nonirrigated plants but gross uptake was greatest for irrigated plants. Uptake for each irrigation decreased with depth with not much difference noted at lower depths. Maximum uptake (2 in. + irrigation) was about 0.1% dose.

1960

30. Cline, J. F. 1960. Potassium, cesium-137, and rubidium-86 relationships in plant uptake, soil diffusion rates and irrigation practices. HW-62037 General Elec. Co., Hanford, Wash.

Results indicate K ion influence on cesium-137 uptake by plants. K^+ reduced Cesium uptake from solution cultures. 0.1 N KCl leaching solution (300 in. in 9 in. column) moved Cs from surface of alkaline (Ephratea) soil but did not elute as it did from an acid soil (Cinnebar). Study with rice and uptake of cesium-137 from contaminated soil indicated "holding" capacity of Cs by soil colloids greater than "uptake" capacity of rice roots, whereas compared to Pendleton's study with Persicaria, "uptake" capacity of plant was greater than retention in pond water.

31. Gileva, C. A. 1960. Coefficients of radioisotope accumulation by freshwater plants. Dok. Akad. Nauk., SSSR. 132: 948-949 (translation).

Very early work concluding that such plants as Spirogyra and Cladophora (filamentous algae) would be useful in decontaminating bodies of water. Data from batch experiments show that these algae are effective sorbers of Cs and Zr (other radionuclides studied also). Cultures used filtered lake water; time = 12-16 days (>4-8 days for equil.) specific activities not given. No chemical analyses of water.

32. Kornberg, H. A. 1960. Radioisotopes and environmental circumstances: The passage of pairs of elements through food chains. In: Radioisotopes in the Biosphere. p. 255-268. Univ. of Minn., Center for Continuation Study. Minneapolis, Minn.

A general review mostly covering work-to-date at Hanford and concluding: First, as the concentration of one member of the pair increases in the environment, the concentration of the other in the receptor does not necessarily decrease in proportion. Second, the ratio of a pair of elements in one link of the food chain bears no necessary constant relationship to the ratio in the next link of the chain. Instead, it may vary with change in concentration of one member of the element-pair and with time. This variability of the OR limits the usefulness of ratios in predicting concentrations in subsequent links of the food chain. Third, the actual measurement of a ratio may lead to errors in usage unless the pair of elements is intimately mixed.

33. Menzel, K. G. 1960. Radioisotopes in soils: Effects of amendments on availability. In: Radioisotopes in the Biosphere, p. 37-46 Univ. of Minn., Center for Continuation Study. Minneapolis, Minn.

Review article written for a symposium concluded that: The effects of amendments on availability of Sr90 in the soil are rather small. Additions of lime, gypsum, fertilizers, or organic matter in practical doses usually reduce uptake by less than half. Only the addition of

calcium-bearing amendments appears to affect the ratio of Sr90 and calcium in the plant products. Amendments may have larger effects on the availability of other fission products, such as Ru106, Cs137, and Ce144, but these fission products are normally less of a hazard than Sr90.

34. Myers, W. M. 1960. Genetic control of physiological processes: Consideration of differential ion uptake by plants. In: Radioisotopes in the biosphere, p. 201-226. Univ. of Minn., Center for Continuation Study. Minneapolis, Minn.

Review article on evidence for selective ion uptake by different plants. Elements covered: Sr, Ca, Ba, I, Cs, Rb, K, Ru, P, Mn, Mo, Mg, Na, Co, Zn, Cu, Fe, Bo, Si, Ni, Ce, La, Y. Most discussion (most published info) on differences between spp, some discussion on varietal differences. Summary of many authors work. Data on chemical composition must be interpreted with caution - many factors influence ion uptake and translocation including chemical form, environmental factors, presence of other elements and fertilizers, stage of maturity, plant part, and kind of plant. Nevertheless, little doubt that a spp. difference does exist.

35. Pendleton, R. C. and K. L. Uhler. 1960. Accumulation of Cesium-137 by plants grown in simulated pond, wet meadow and irrigated field environments. Nature 185: 707-708.

Polygonum persicaria (smartweed) grown under various conditions and soil surface spiked with 72.3 μ c Cesium-137 after plants well established. Same soil used, Ephrata SL. Plant apical bud, stem and first 2 leaves harvested periodically for 36 days. Uptake greatest from pond condition with probably uptake thru stem and adventitious roots -- similar results to solution culture technique; irrigated treatment results similar to levels noted in natural habitat. 450 fold difference (increase) between "irrigated" and "pond" tests. "Wet meadow" was intermediate.

36. Romney, E. H., W. L. Ehler, A. H. Lande, and K. H. Larson. 1960. Some environmental factors influencing radiostrontium uptake by plants. Plant and Soil 12: 41-48.

Laboratory tests indicate reduction in uptake of ⁹⁰Sr from solution cultures by barley or beans due to a lowering of root temp. from 17 to 7°C or a reduction in light intensity from 1000 to 450 f-c. Shortening of photoperiod also decreased uptake. Species differences in uptake from flats grown in greenhouse also noted. In all cases, leaves or forage showed highest d/s/gm values.

37. Uhler, R. L. and F. P. Hungate. 1960. Relative availability of some strontium-90 compounds in soil. Nature 187: 252-253.

The relative availability to bean plants grown in soil of 7 different strontium compounds was studied with time and soil (3 types) as variables. Uptake from relatively insoluble forms was similar and 10 fold less than soluble forms in acidic soil. For basic and calcareous soils uptake of soluble forms was Ca, 50% that in acid soil; similar true for insoluble forms except CO_3 and HPO_4 salts which were considerably less available, however, the CO_3 form increased in uptake with time (doubled). Based on these results and other field trial, authors conclude that time and possible chemico-physico changes in soil are probably unimportant in long term strontium uptake from soil.

38. Willard, W. K. 1960. Avian uptake of fission products from an area contaminated by low-level atomic wastes. *Sci.* 132: 148-150.

Data represent a survey during 1958-59 of body burdens of resident bird populations at White Oak Lake bed. Birds were collected during summer or winter. Summer feeders were obtaining Sr and Cs thru food chain (primarily Carabid Beetles) whereas winter birds were looking for seeds and consuming contaminated soil in the process.

1961

39. Christenson, C. W. and E. B. Fowler. 1961. Depth of feeding as it affects the concentration of radioactivity within the plant. *J. Agric. and Food Chem.* 9: 98-100.

Rooting depth affects the degree of plant uptake from soil if entire soil profile is not contaminated. Study described with ^{137}Cs soil treated 0-2 1/2, 0-5, 0-10, 0-60 inches. Data expressed as percent of 0-60 treatment. All values were less than 0-60 treatment on days sampled (beginning after 46 days from planting) indicating root penetration very rapid for alfalfa, lettuce and "grass".

40. Crossley, D. A. and J. F. Howden. 1961. Insect-vegetation relationships in an area contaminated by radioactive wastes. *Ecol.* 42: 302-317.

Early studies on plant succession & insect relations on White Oak Lake bed. Herbivorous insects noted to take up significant amounts of radionuclides from vegetation (leaves) Cs^{137} , Sr^{90} , Co^{60} , Ru^{106} , ZrNb^{95} . Details of Cs and Sr presented here. Insect burdens were high (28% of soil for Sr and 1% for Cs) but populations (biomass) low, and not much danger from contamination spread standpoint. Insect-plant ratios were 1.0 to 0.7 for Cs and .05 to 0.1 for Sr. Cs apparently is eliminated less rapidly and builds up in insect relative to Sr. Predaceous insect values were close to herbivorous insects. Sr^{90} content of Polygonum (smartweed) was greater than soil Sr^{90} .

41. Crossley, D. A. and J. H. Schnell. 1961. Comparative elimination of radiocesium and radiostrontium by grasshoppers. *Ann. Entomol. Soc. Amer.* 54: 459-461.

Data from studies on White Oak Lake bed. Field observations indicated small and medium sized grasshoppers (Melanoplus femur-rebrum and M. differentialis, resp.) reached different equilibrium concentrations of Sr and Cs. Lab studies indicate elimination of Cs is less rapid than Sr, thus Cs builds up higher concentrations relative to Sr. Also noted in field that insects Cs burden approximates plant food but insect Sr about one order of magnitude less than plant concentration. Insect (grasshopper) body burdens increase with size.

42. DeSelm, H. R. and R. E. Shanks. 1961. The ecology of White Oak Lake bed: a radioactive waste area. Part II. Recent Advances in Bot. 2: 1359-1363.

Results of vegetation study on White Oak Lake bed are described. Cs137 concentrations varied between 3 and 1800 pCi/gm but 50% spp. examined were on the order 100-500 pCi/gm. Comparison of different spp. growing on same soil indicates that variability is in part genetic. Carex and Juncus were examined carefully and various correlations with environmental factors are reported.

43. Mills, H. L. and L. M. Shields. 1961. Root absorption of fission products by Bromus rubens L. from the AEC Nevada test site soil contaminated by an underground nuclear explosion. Rad. Bot. 1: 84-91.

Neubauer technique using nuclear creater soil ("Blanca" event) and a local weed Bromus rubens. Results similar to uptake reported from "Bravo" soil, but uptake of Ce, Ru, Zn greater than reported elsewhere. Most activity was in leaf and stem tissue.

44. Nishita, H., E. M. Romney, and K. H. Larson. 1961. Uptake of radioactive fission products by crop plants. J. Agric. Food Chem. 9: 101-106.

A good review of work through 1960 on uptake through root systems.

1. Relative plant uptake: $Sr \gg I > Ba > Cs, Ru > Ce, Y, Pm, Zr-Nb > Pu$
2. Soil types: Sr uptake greatest from acid soils, least from calcareous soil; Sr uptake by plants corresponds with water soluble Sr;
3. Distribution within plant body: Greatest concentrations found in leaves but least pronounced with Cs; Ce, Zr-Nb concentrated in roots (Sr to some extent and results in $Sr OR < 1$ for most plants) Species difference noted.
4. Chemical (soil) factors influencing uptake: Ca level for Sr uptake; OM increase reduces Sr uptake.
5. Chemical form of contaminant: uptake of nuclide is proportional to solubility of salt.

45. Tukey, H. B., S. H. Whittwer, and M. J. Bukovak. 1961. Absorption of radionuclides by aboveground plant parts and movement within the plant. J. Agric. Food Chem. 9: 106-113.

Study mostly concerned with fallout, but section on loss from leaves by leaching is of interest. Domestic (geranium) and crop plants used and Sr only fission product of interest studied but data readily show that many ions (both cations and anions) are easily leached and that plant mechanisms are such that replenishment occurs.

1962

46. Evans, E. J. and A. J. Dekker. 1962. Comparative Sr90 content of agricultural crops grown in a contaminated soil. Can. Jour. Plant Sci. 42: 252.

36 species of crop plants were grown in common soil spiked with Sr90. Results reported as $\mu\text{CiSr/gmCa}$ in leaf tissue. Cereals ranged 3.16-3.94; forage crops 3.14-6.78; vegetable crops 2.97-4.16. Not much difference noted in Sr uptake relative to Ca.

47. Haghiri, F. 1962. Sr90, Zr95 and Cs137 accumulation in corn plants as influenced by soil temperature. Jour. Agron. 54: 273-279.

Article describes results of experiment with 3 week old corn plants and uptake of Sr90, Cs137 and Zr95 after 4 day soil exposure (surface). Variables were root temp. of 50, 60, 70 and 80°F. 70°F resulted in highest uptake of Sr and Cs. No Zr uptake was detected. Temperature of shoots, diurnal variation in temp. or exchangeable or available radionuclides are not discussed.

48. Kaye, S. V. and P. B. Dunaway. 1962. Bioaccumulation of radioactive isotopes by herbivorous small mammals. Health Physics 7: 205-217.

Report on results of pilot study on small mammals associated with low level waste areas at ORNL. Examined muskrats, cotton rats, rabbits and three spp. of mice. Ce and Ru were not appreciably taken up from gut although present in GI contents. Cs, Co, Zn and Sr readily taken up and maybe only ones accumulated. However, uncertainty of level of contamination of feed makes CF calculations difficult. Zr-Nb slightly taken up. Animal concentrations of nuclides depends on home range and size of contaminated area.

49. Nelson, D. J. 1962. Clams as indicators of Strontium-90. Sci. 137: 38-39.

Freshwater clams accumulate Sr in their shells and thus make good indicator organisms for Sr90 contamination in river systems. They are active all year long and would tend to integrate the Sr value over season and in same Sr/Ca ratio as in water. Values on specific activity (atoms Sr90 per atoms Sr) also calculated. Suggest short-lived molluscs such as physid snails may be useful as short-term indicators of Sr90.

50. Pickering, D. C. and J. W. Lucas. 1962. Uptake of radiostrontium by an alga and the influence of calcium ion in the water. *Nature* 193: 1046-1047.

Laboratory studies on algal culture uptake of Sr when Ca^{++} varied, $\log \text{CF}_{\text{Sr}}$ linear with $\log \text{Ca}^{++}$ water. Although coefficient correlation not given, $\log \text{CF}_{\text{Ca}}$ linear with $\log \text{Ca}^{++}$ water but slightly different than Sr curve. Difference attributed to adsorbed Ca on algae which is exchangeable with solution Sr. Other ions (Mg^{++} , eg.) suspected of having effect. Results show CF_{Sr} have no real meaning unless considered in light of Ca^{++} levels.

1963

51. Aleksakhin, R. M. 1963. Radioactive contamination of soil and plants. Transl. from Russian by the Isreal Program for Scientific Translations, Jerusalem, 1965. Ch. 2: Uptake and accumulation of radioactive fission fragments, certain products of induced radioactivity and plutonium-239 by plants and the effect of these radioisotopes on plants.

Book is Russian review of subject through 1961. (Ch. 2 reviewed here). Plants are capable of accumulating radioelements from aqueous solutions and may result in concentrations 2-4 orders of magnitude higher than the media. Plant absorption from soil and subsequent buildup may result in a plant concentration one order of magnitude higher than the soil. Eg. for Sr90 concentration from soil uptake is 1/30 that from solution yet plant content is 5-10 times soil content (cited from Russian works). Chapter 4 is good review of "biodecontamination" of waters.

52. Auerbach, S. L., et al. 1963. Radioactive waste area and radiation effects studies. Health Phys. Div. Ann. Prog. Rept., July 1963. ORNL-3492. Oak Ridge Natl. Lab.

Continuing study since 1962 described and updated. Conc. in White Oak Lake bed 0-1" > 2-4" for Ru106 but not so for Cs137, Co60 and Sr90 which were rather evenly distributed. Plant conc. of Ru, Cs, Co less than soil 0-4". Polygonum (smartweed), Rumex, and Solidago were plant taxa with high conc. relative to other spp. Differences in Sr90 and Ru106 contents in Polygonum and Aster thought to be due to soil moisture where plants grow i.e. polygonum grows in wetter areas.

53. Auerbach, S. I. and J. S. Olson. 1963. Biological and environmental behavior of ruthenium and rhodium. In: Schultz, V. and A. W. Klement (ed.) Radioecology: Proc. of the First Natl. Symp. of Radioecology, 1961. Reinhold and AIBS. p. 509-520.

Because of its ability to exist in several valence states and complex with other compounds (e.g. Nitrates), Ru-Rh is very mobile in ecosystems particularly where water is involved (waste ditches, etc.). Data

presented and reviewed for marine and freshwater; terrestrial environments also discussed. For beans and clover highest concentrations are in roots but some translocation upward, especially to leaves. $RuCl_4$ very volatile starting at 45C, almost 100% at 110C.

54. Brungs, W. A. 1963. The relative distribution of multiple radionuclides in a fresh-water pond. Ph.D. Dissertation, The Ohio State University; Zoology. University Microfilms 64-1245, Ann Arbor, Mich.

A large pond was constructed and stocked with producer and consumer organisms. $Co60$, $Zn65$, $Sr85$ and $Cs137$ were used in the pond as well as lab experiments. Co was associated with suspended solids and Ca with bottom sediments although all radionuclides very active in system. Co tended to accumulate in algae and tadpoles, Sr in crayfish exoskeleton and carp bone, and Cs in carp and crayfish flesh, tadpoles and algae. Snails were moderately important.

55. Crossley, D. A., Jr. 1963. Movement and accumulation of radiostrontium and radiocesium in insects. In: Schultz, V. and A. W. Klement (ed.) Radioecology: Proc. of the First Natl. Symp. on Radioecol., 1961. Reinhold and AIBS, p. 103-106.

Plant-insect transfers are on the order of $Sr90 = 10\%$ and $Cs137 = 80\%$ and differences were noted for different plant-insect pairs. Grasshoppers feeding on smartweed were noted to transfer the most activity. Postulated that if all insects left at one time, radionuclide removal would be on order of 3 μCi $Sr90$ (and 3 μCi $Cs137$) which is the amount of Sr in 10 Kg soil. Insects come to equilibrium rapidly with respect to consumption and body elimination. Estimated about 6% of radionuclides in plants passed through insect trophic level. Cs and Sr not accumulated in insect hard tissue. Birds were noted (another paper for detail) to contain more $Sr90$ (due to bone retention) than insects they utilized for food.

56. Davis, J. J. 1963. Cesium and its relationships to potassium in ecology. In Schultz, V. and A. W. Klement (ed.). Radioecology: Proc. of the First Natl. Symp. in Radioecol., 1961. Reinhold and AIBS. p. 539-556.

A rather comprehensive review of cesium and its ecology is presented. Central theme is fallout Cs and studies through about 1960.

57. Deselm, H. R. and R. E. Shanks. 1963. Accumulation and cycling of organic matter and chemical constituents during early vegetational succession on a radioactive waste disposal area. In: Schultz, V. and A. W. Klement (ed.). Radioecology Proc. of the First Natl. Symp. on Radioecology, 1961. Reinhold, and AIBS. p. 83-96.

Data presented on 5 yr. study of White Oak Lake following drainage. Plant material was noted to be surface contaminated, thus a scrubbing procedure

was developed to remove external radioactivity. No data provided for removal by leaching of chemical constituents or radioactivity. Forbs and Juncus accumulated most of radioelements analyzed whereas grasses and Cyperaceae were lowest. Analyzed for Sr90, trivalent rare earths, Ce144, Cs137, Co60, Ru106 and ZrNb95.

58. Olafson, J. H. and K. H. Larson. 1963. Plutonium, its biology and environmental persistence. In: Schultz, V. and A. W. Klement (ed.). Radioecology: Proc. of the First Natl. Symp. on Radioecology, 1961. Reinhold and AIBS. p. 633-642.

A good review, with some original data, up to about 1960. Most interest is expressed in fallout Pu and the main route of inhalation to man. Some background information from IITS and New Mexico also discussed.

59. Ophel, I. L. 1963. The fate of radiostrontium in a freshwater community. In: Schultz, V. and A. W. Klement (ed.). Radioecology: Proc. of the First Natl. Symp. on Radioecology, 1961. Reinhold and AIBS. p. 213-216.

Studies on Perch Lake following contamination with Sr90 waste are described. Slow build-up in fish contrasted with lab studies and their rapid equilibration. Difference here is that CF values are based on water-bone not soft tissues. Local food web is briefly discussed. Animal flesh samples equilibrate in 2-3 years whereas bone in 4-5 years.

60. Rasmussen, D. C., L. H. Smith and W. M. Myers. 1963. Role of the genotype in controlling accumulation of Strontium-89 by plants. Nature 198: 1008.

Work described on varietal difference of Sr uptake in barley and wheat when grown on same soil and similar conditions. In all, highest shoot concentrations were in leaves followed by stems and grain. All varieties (6 each spp.) differed significantly in leaf, stem or grain contents. Concluded; large genotypic differences for these and probably many spp. Difference in plant part content probably due to both uptake and transport.

61. Romney, E. M., H. Nishita, J. H. Olafson and K. H. Larson. 1963. Root transfer of fission products from contaminated soil. Soil Sci. Soc. Amer. Proc. 27: 383-385.

Greatest plant uptake of mixed fission products occurred when (1) levels of contamination were highest, and (2) dose was applied to surface, as opposed to same dose mixed throughout soil. Suspected that greater root mass and oxygen availability at surface were important factors. Leaf activity was highest where Sr accounted for about 50% of total beta.

62. Shanks, R. E. and H. R. DeSelm. 1963. Factors related to concentration of radiocesium in plants growing on a radioactive waste disposal area. In: Schultz, V. and A. W. Klement (ed.) Radioecology: Proc. of the First

Natl. Symp. on Radioecol., 1961, Reinhold and AIBS. p. 97-102.

Correlations of soil properties with Sr90, Cs137, Co60 content in Carex frankii were determined. Carex Cs concentration most closely related to total Cs (0-2 in. soil), Exch. Cs, Ca and Mg (0-6 in. soil) and pH. These 5 factors accounted for only about half of plant Cs variation, however.

1964

63. Barber, D. A. 1964. Influence of soil organic matter on the entry of Cesium-137 into plants. *Nature* 204: 1326-1327.

Results on cesium uptake from soils of varying OM content suggest that cesium retention in soil is inversely proportion to OM content. When OM content is low, the exchange capacity of soil is almost entirely due to clays which fix cesium to a much greater extent than OM. High cesium uptake by ryegrass was noted from soils with greatest OM content.

64. Harvey, R. S. 1964. Uptake of radionuclides by fresh water algae and fish. *Health Physics* 10: 243-247.

Object of research was to find one fish to sample as representative of edible fish population for environmental monitoring program. Data indicate fish (Bluegill, Bass, Bullhead) selectively concentrate Cs, Zn and Sr from environment that also contains Ce, Ru, Zr-Nb and Co (etc.). Relative contents of filamentous bluegreen algae was Zn > Cr > Ce > Ru > Co, Zr-Nb, Cs > Sr.

65. King, S. F. 1964. Uptake and transfer of Cs-137 by Chlamydomonas, Daphnia, and bluegill fingerlings. *Ecol.* 45: 852-859.

The uptake, accumulation and transfer of Cs137 for a simple food chain were studied. Uptake by all organisms was greatest at 22C. Chlamydomonas uptake rose with an increase in available Cs up to 1 ppm and decreased with increasing algal densities. A spp. difference was noted in Daphnia - a factor of three. Direct uptake from water by bluegill was negligible but retention from food was 13-14%.

66. Nelson, D. J. 1964. Interpretation of radionuclide uptake from aquatic environments. *Nuclear Safety* 5(2): 196-199.

The specific activity approach is discussed: there are 4 main assumptions:

1. There is no biological difference between isotopes of a nuclide; this is generally true except for H₃ and C₁₄.
2. Biological t 1/2 is known - (No consequence under chronic and "steady state" conditions for long-lived radionuclides).
3. Organisms are in equilibrium with their environment.
4. The concentration of the stable element in the environment is known.

$$\text{Thus: } \frac{\text{stable nuclide in organism}}{\text{stable nuclide in environment}} = \frac{\text{radionuclide in organism}}{\text{radionuclide in environment}}$$

Used to predict amount of radioactivity in organism from environmental determinations and stable element concentrations in the organism.

67. Whitkamp, M. and M. L. Frank. 1964. First year of movement, distribution and availability of Cs-137 in the forest floor under tagged tulip poplars. *Rad. Bot.* 4: 485-495.

Experiment where trees were tagged with Cs-137 thru trunk in native forest situation. During first year Cs was rapidly translocated to roots and leaves. Considerable Cs also leached from foliage ($3 \mu\text{Ci}/\text{m}^2$) onto ground. As leaves matured Cs leached more easily; together with decay of fallen leaves in fall forest floor litter increased in Cs from $7-82 \mu\text{Ci}/\text{m}^2$. Forest floor Cs was in upper 2 cm of mineral soil and litter and was readily available for root uptake. 3 months after contamination 85% Cs on floor was in roots. About 25% after 1 yr.

68. Wimber, D. E. 1964. Effects of intracellular irradiation with tritium. In: *Advances in Radiation Biology*, Vol. 1. Academic Press, New York 1964. p. 85-115.

A review which discusses radiation and chemical effects of tritium mostly at cellular level. Tritium is not biologically equivalent to proteium: *Chlorella pyrenoidosa* uptake of ^3H was only 50% of expected based on equivalence. Chromosome breakage noted in onion and Vicia root tip cells grown in 0.2 or 0.375 $\mu\text{Ci}/\text{ml}$ for 18 or 10 hrs, respectively. Species differences in response may vary several orders of magnitude.

69. Wiser, C. W. and D. J. Nelson. 1964. Uptake and elimination of cobalt-60 by crayfish. *Amer. Midl. Natur.* 72: 181-202.

Results of rather comprehensive study with live or dead crayfish are described. Noted that about half the uptake is adsorbed onto exoskeleton. Most absorbed cobalt also associated with exoskeleton, thus 95% lost at molting when cobalt-60 supplied in medium. CF appear to be about 200 when large volumes of solution were used.

1965

70. Adams, W. H., C. W. Christenson and E. B. Fowler. 1965. Relationship of soil, plant and radionuclide. p. 30-51. In: Fowler, E. B. (ed.). *Radioactive fallout, soils, plants, foods, man.* Elsevier. pp. 317.

A review synthesizing information to approximately 1964. Most data are from UCLA, Hanford and Oak Ridge which are reported in original from elsewhere.

71. Birkle, D. E., J. Letey, N. T. Coleman and W. F. Richardson. 1965. Uptake by plants of Cs-137, Ce-144, and Y-91 as influenced by rhizosphere oxygen treatments. *Soil Sci.* 99: 93-97.

Results of this study were inclusive as to the role of oxygen in the root environment on the uptake of radionuclides except that different plants responded in different ways. Until uptake mechanisms are better understood, effect of oxygen must be studied from an empirical approach. Little effect noted for barley and Cs uptake from soil when O_2 tensions reduced.

72. Harvey, R. S. 1965. Savannah river plant biological monitoring program. Health Phys. 11: 211-214.

The biological monitoring program at SRP is briefly discussed and a few data presented on tissue concentrations and CF values for some indicator organisms. Algae, bluegill, ringneck duck and cottontail rabbit routinely sampled.

73. Parker, H. H., R. F. Foster, I. L. Ophel, F. L. Parker and W. C. Reinig. 1965. North American experience in the release of low-level waste to rivers and lakes. In: Third Intl. Conf. on the Peaceful Uses of Atomic Energy, Geneva, 1964. Vol. 14: 62-68, Environmental Aspects of Atomic Energy and Waste Management, United Nations, New York.

Review gives a brief synopsis of river environmental surveillance at Hanford, Oak Ridge, Savannah River, and Chalk River (Canada) nuclear installations. Data are given for waste discharge (primarily reactor coolant) into major rivers and Lakes or Ponds up to 1963. Most activity is retained in sediment systems within a few 10's Km's from reactor discharge site or in estuaries of large rivers.

1966

74. Echo, J. and D. B. Hawkins. 1966. Algal influence on radionuclides in settling ponds. Nature 209: 1105-1107.

Results from study on pond algae associated with AEC NRTS settling basins for low level waste. Typical algae of ponds grown in synthetic medium with SR85 or CS137 to determine nuclide uptake. Dead, tagged algae also allowed to decompose into non-radioactive media. The solutions used above, plus one without algae were used to determine K_d values to see if algal growth or decomposition (possible chelation) stages had influence on K_d . Data showed no effect but during decomposition a larger % of Cs (>2 times) was released relative to Sr.

75. Garder, K. and O. Skilberg. 1966. An experimental investigation on the accumulation of radioisotopes by fresh water biota. Arch. Hydrobiol. 62: 50-69.

The accumulation of Cs, Ce, Sr, Ru and Zr-Nb by sediments, algae and vascular plants, invertebrates, and fish was determined under artificial conditions, i.e., troughs and tanks. Cs and Ce were sorbed to sediments

to great extent, but Cs conc. was least, for nuclides studied, in algae study. Vascular plant uptake lower than algal uptake. Invertebrates and fish accumulations reflected food habits thus emphasizing food web relationships.

76. Menzel, R. G. 1966. Soil-plant relationships of radioactive elements. In: Hungate, F. P. (ed.) Radiation and Terrestrial Ecosystems: Proc. of the Hanford Symp., 1965. Pergamon Press. p. 1325-1332.

A good review to 1965. When a radioactive element is added in soluble form to soil, its concentration in plants growing on that soil may be several orders of magnitude greater or less than its concentration in the soil. The concentration factor depends mainly on chemical properties of the element, but it may vary one or two orders of magnitude depending on chemical properties of the soil and species or part of plant. Leaf tissue is expected to have the highest concentration of most elements that are appreciably absorbed from soil but elements with metabolic functions may be more concentrated in the seed, and many that are very little absorbed may be more concentrated in the roots and lower stems.

77. Reichle, D. E. and D. A. Crossley, Jr. 1966. Radiocesium dispersion in a cryptozoan food web. In: Hungate, F. P. (ed.). Radiation and Terrestrial Ecosystems: Proc. of the Hanford Symp., 1965. Pergamon Press. p. 1375-1384.

Data also presented for seasonal body burdens and calculations made on consumer-to-food ratios (CF) for Cs137. Mean food concentrations (litter) ~ 25 pCi/gm; Saprovores ~ 4.9 pCi/gm and predators ~ 2.5 pCi/gm. Thus consumer-to-food ratios were 0.2 and 0.5. Previously reported herbivorous insects at 0.8 and herbivore-to-predator about 1.0. Transfer efficiency greatly influenced by migration.

78. Russell, R. S. 1966. Radioactivity and Human Diet. Pergamon Press. p. 552.

A very comprehensive and well written review covering most aspects of radioecology (with particular reference to human diet factors) up to date of publication. Provides a quick reference for more common and well known information including explanations and interpretation. Extensive literature citations. Section on plant uptake in terrestrial food chains is especially useful.

79. Squire, H. H. 1966. Long-term studies of strontium-90 in soils and pastures. Rad. Bot. 6: 49-67.

Results from expt. where strontium-90 added to soil surface of large pots and either cropped with ryegrass or left bare. Downward movement depends on Ca^{++} status of soil, least in calcareous soils. After 3 yrs. Sr had moved >20 cm in calcareous soil but only 6% of total >15 cm deep. Downward movement unaffected by cropping. Plant uptake varied

with Ca^{++} content of soil; - least for calcareous soil. Strontium-90 physio-chemical changes with time reduced available Sr < 10%. Sr/Ca plant linear with .01M CaCl_2 extractable soil Sr. Fertilizer treatments had little affect on calcareous soil - considerable effect on other soils. Sr/Ca plant changed with time (within and between years) as Sr moved down through soil profile.

80. Squire, H. H. and L. J. Middleton. 1966. Behavior of Cs-137 in soils and pastures: a long term experiment. *Rad. Bot.* 6: 413-423.

Complimentary expt. to that on Sr-90 (No. 79). After six years carrier free Cs-137 moved about 3 cm downward in calcareous soil and was unaffected by cropping or fertilizer treatments. Cs-137 uptake decreased during first 3 yr. cropping presumably due to increased permanance of fixation because effect was least on sandy and greatest on clay soils. After 3 yrs. fixation apparently complete. Uptake from soil with lowest clay content and lowest exch. K was 10 times greater than soil with highest K content.

81. Wilson, D. O. and J. F. Cline. 1966. Removal of plutonium-239, tungsten-185 and lead-210 from soils. *Nature* 209: 941-942.

Neubauer technique indicates very small amount of plutonium-239 taken up by 18 day old barley seedlings. Leaf-soil Cf $\sim$.0001. Greatest uptake from acid soil, least from calcareous soil. Plutonium-239 added as $\text{Pu}(\text{NO}_3)_3$ at 10 $\mu\text{Ci/gm}$ soil. Standard leaching solution failed to remove much plutonium. 0.1 N HNO_3 removed greatest amount (0.64%). Pu uptake was least of three isotopes studied.

1967

82. Agnedal, P. O. 1967. Calcium and strontium in Swedish waters and fish and accumulation of 90-Sr. In: Aberg, B. and F. P. Hungate (eds.) 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 879-896.

Calculations show that in lakes with about 2 mg Ca/l, the strontium accumulation factor fish muscle tissue is between 100-200, while in lakes with 20-40 mg Ca/l it is about 10, and in Tvaren and probably even in fresh water with high calcium content, about 100 mg/l, it is not more than 1. Some values below 1 indicate a discrimination against strontium.

83. Alexahin, R. H. and M. H. Ravikovich. 1967. On the behavior of alkaline-earth elements calcium, magnesium and strontium in a forest biogeocoenosis (ecosystem). In: Aberg, B. and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 443-452.

Data are mostly for trees (distribution within a birch tree) but some O.R.'s for soil, litter, herbaceous vegetation. Sr/Ca O.R. for herbs-soil = 3.4; Sr/Mg O.R. herbs-soil = 12.5. These values are highest reported here.

84. Bovard, P. A., Grauby and A. Gravier. 1967. The uptake of strontium by ryegrass. In: Aberg, B., and F. P. Hungate, (eds.) 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 453-465.

Not a factorial designed experiment - each K salt treatment considered separately. The application of certain potassium salts enhances the concentration of strontium-90 in ryegrass. The mean activity per unit weight increases by about 30% in samples treated with potassium sulphate, carbonate or oxalate. Samples treated with the oxalate were to some extent stunted as the mechanism of absorption was probably disturbed. Potassium nitrate does not affect the content of strontium-90 in ryegrass; it encourages growth, and the increased weight of plant substance produced in this case leads to an increase in the total amount of strontium-90 accumulated in the leaves.

85. Cavalloro, R. 1967. Data on the accumulation, distribution and elimination of Sr85, I131 and Cs137 in various insect species. In: Aberg, B. and F. P. Hungate (eds.) 1967, Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 601-608.

Article consists of a series of tables and graphs depicting % distribution among body tissues for insect immature and adult forms; biological half-lives; and accumulation (body burden in cpm) over periods up to 7 days. Moths, butterflies, grasshoppers and crickets considered.

86. Ekman, L. 1967. Mechanisms of uptake and accumulation of radionuclides in terrestrial animals. In: Aberg, B., and F. P. Hungate (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 547-560.

A review article with 126 references up to 1966. Author notes that the most important route into animals is through ingestion of food and gastrointestinal tract. Nearly all elements can be absorbed depending on concentration and solubility of chemical form. Inhalation is important especially for radioactive gases and high specific activity particles. Many elements can enter body through percutaneous absorption - again dependent on solubility. Several organs accumulate elements selectively, thus distribution and retention within the animal body is varied. Many factors involved including species of animal, age and chemical form of element and mode of entry. Retention times are, in part, dependent on body weight.

87. Gustafson, P. F. 1967. Comments on radionuclides in aquatic ecosystems. In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 853-858.

Review and discussion of fallout cesium and other radionuclides. Overall CF relating edible fish to lake water was 2760. CF values for experimental three link fish to fish food chain were: small mixed fish - perch (1.35), perch - northern pike (4.81); overall (3.90).

88. Harvey, R. S. and R. Patrick. 1967. Concentration of ^{137}Cs , ^{65}Zn and ^{85}Sr by fresh-water algae. *Biotech. and Bioeng.* 9: 449-456.

Lab study on uptake of Sr, Cs and Zn by three spp. each of diatoms, bluegreen and filamentous algae. Two culture methods were compared (batch vs continuous flow) and two levels of contamination were used. Nuclides were either added separately or as a mixture. Conclusions - batch culture produced higher uptake and higher CF Cs=2 times; no consistent effect of dose amount noted; no consistent spp. difference noted when surface to volume ratios considered for Cs uptake; no significant difference whether Cs added alone or in mixture; Zn uptake much greater than Cs or Sr and CF water are in general agreement with those reported in literature.

89. Kovalsky, V. V., I. E. Vorotnitskaya and V. S. Lekarev. 1967. Biogeochemical food chains of uranium in aquatic and terraneous organisms. *In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 329-332.*

Studied uptake of U by algae and fish from enriched lake water. All organisms concentrated U compared to water, but appears that U discriminated against at each step of consumer food chain. Predatory fish accumulated less than herbivores. Skin and flesh contained 93% of body burden. Terrestrial plants showed U uptake (CF=0.23) and sheep accumulated U from feed 5-8 times control animals.

90. Krieger, H. L., B. Kahn and S. Cummings. 1967. Deposition and uptake of ^{90}Sr and ^{137}Cs in an established pasture. *In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 59-72.*

A supporting experiment studied relative uptake of Sr and Cs by ryegrass roots as a function of radiotracer depth in soil. Uptake of Sr or Cs was greatest from surface or 2.5 cm applications and decreased to 15 cm. Sr uptake always greater than Cs by factor 10.

91. Marey, A. N. and H. H. Saurov. 1967. Material for assessment of the role played by food chains in ^{90}Sr migration from fresh water reservoirs into the diet of man. *In: Aberg, B., and F. P. Hungate (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 135-142.*

Study of fallout Sr through aquatic food and farm products to man. Fish is greatest source of Sr from aquatic habitat whereas cereals (bread products) are greatest for terrestrial habitats. Fish Sr content varied inversely with water Ca^{++} .

92. Myttenaere, G., Verfaillie, and P. Bourdeau. 1967. Uptake and distribution of ^{144}Ce in *Oryza sativa*. In: Aberg, B., and F. P. Hungate (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 437-443.

^{144}Ce displays a distribution gradient in rice, the younger the plant the lower the root/shoot ratio for ^{144}Ce concentrations because of the higher content of ^{144}Ce in basal organs of shoot; roots contained about 8 times more $^{144}\text{Ce}/\text{gm}$ than leaves.

93. Neal, E. C., B. C. Patten and C. E. DePoe. 1967. Periphyton growth on artificial substrates in a radioactively contaminated lake. Ecol. 48: 918-924.

An artificial substrate (polyethylene tape) suspended vertically in White Oak Lake for 9 weeks supported various algal communities. Maximum biomass after 2 weeks. Autotrophic organisms near surface, heterotrophs and auxotrophs deeper. Radioactivity in biomass greatest near bottom where dissolution and resuspension important. Bluegreen algae concentrated Co, an essential element to them. Tape accumulated $\text{Zn} > \text{Cs} > \text{Co} > \text{Ru}$ but Zn in water undetectable.

94. Nelson, D. J. 1967. The prediction of ^{90}Sr uptake in fish using data on specific activities and biological half lives. In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 843-851.

A good agreement was observed between the specific activity of ^{90}Sr in water and white crappie bone, indicating that it is possible to predict ^{90}Sr concentrations in fish when the specific activity of the water is known. The specific activity approach with ^{90}Sr is considered superior to the use of ^{90}Sr -Ca ratios. This was illustrated by the fact that among five species of Clinch River fish, differences in either the Ca or Sr concentrations would affect the accuracy of predictions based on Ca concentrations.

95. Ophel, I. L. and J. M. Judd. 1967. Experimental studies of radio-strontium accumulation by freshwater fish from food and water. In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 859-867.

Under natural conditions the major pathway for Sr into fish is food (because of biological concentration from water). Many factors affect food-Sr accumulation. The experiments described indicate a wide variation in Sr retention from food by fish. Some of the factors affecting retention are: (1) food composition, (2) specific activity of food, and (3) feeding habits of the fish. Under some circumstances,

food may contribute more radiostrontium than water to the body-burden of fish living in a contaminated environment.

96. Romney, E. II., A. J. Steen, R. A. Wood and W. A. Rhoads. 1967. Concentration of radionuclides by plants grown on ejecta from the Sedan thermonuclear creating detonation. In: Aberg, B., and F. P. Hungate (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 391-398.

Radionuclide in greatest concentration in plants was radiotungston, apparently an activation product from the material in the nuclear device, Y90, Rh102, Eu152 and Eu154 detected in native plants was leaf surface contamination. Cs137 plant conc. increased over 3 yr. period in alfalfa grown on ejecta. Sr90 and Ce144 decreased in concentration pCi/gm dry tissue.

97. Russell, R. S. 1967. Uptake and accumulation of radioactive substances in terrestrial plants - the radiobiological aspect. In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 367-382.

Author calculates MPC - soil Sr as 5 Ci Sr90/km² for fallout and milk in diet of man. Cs considered also. Concludes surface contamination more important than soil accumulation and subsequent uptake.

98. Timofeeva, N. A. and N. V. Kulikov. 1967. The role of freshwater plants in accumulation of 90-Sr and its distribution over the components of reservoir. In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 835-841.

Living as well as dead plants tend to accumulate 90-Sr, indicating that sorption is important in aquatic spp. In general 400 ppm Ca⁺⁺ reduced CF values by a factor of 6 to 14. Because of sorption, detritus is very important in aquatic systems. 50 ppm Hg⁺⁺ reduced CF by factor about 5.

99. Townsley, S. J. 1967. The concentration of 90-Sr and other nuclides of strontium in fish. In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 867-878.

Studies on 85-Sr, 89-Sr and 90-Sr are described for euryhaline fish reared in either saltwater or freshwater. CF values are given - no difference in fish uptake from either type of water up to 100 μ Ci/l. Higher freshwater conc. showed lower accum. rates. No difference between isotopes noted.

100. Verfaillie, G., C. Myttneare and P. Bourdeau. 1967. Factors involved in the accumulation of fallout radionuclides in irrigated rice and meadow plants. In: Aberg, B., and F. P. Hungate. (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 429-436.

Auxillary expt. compared Sr and Cs uptake by rice from solution. Cs whole plant uptake was 62%, Sr 16% of dose. CF Cs=225 and Sr=28 for roots; Cs=57 and Sr=48 for leaves. Concluded rice capable of greater uptake of Cs than Sr but strong soil retention limits Cs uptake in field.

101. Verkhovskija, I. N., P. P. Vavilov and V. I. Maslov 1967. The migration of natural radioactive elements under natural conditions and their distribution according to biotic and abiotic environmental components. In: Aberg, B., and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 313-328.

Average plant ash content of U determined for trees growing on ore deposits. Shoot portions of trees varied from 5 to 40 x 10⁻⁶% of < .001 mm soil fraction. General plant uptake from ore is radium > uranium > thorium. Small amounts U noted in small mammals and fowl.

102. Waller, J. D. and J. S. Olson. 1967. Prompt transfers of Cs-137 to the soils of a tagged Liriodendron forest. Ecol. 48: 15-25.

Second in a series on a Cs-137 tagged Liriodendron forest. Rapid movement into roots noted previously. At end of first growing season, of total Cs in soil about half in roots and half from colloid exchange, root exudation, root death and leaching from roots. Concluded Cs tenaciously held in soil but once taken up it is rapidly distributed throughout the ecosystem.

103. Wicker, F. W., G. C. Farris and A. H. Dahl. 1967. Concentration patterns of 90-Sr, 137-Cs, and 131-I in wild deer population and environment. In: Aberg, B. and F. P. Hungate, (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 621-633.

Article describes observed and predicted uptake of Sr, Cs and I by deer from fallout on forage plants. Close predictions possible if know plant contents of radionuclides.

104. Włodek, S. 1967. The behavior of 137-Cs in freshwater reservoirs, with particular reference to the reactions of plant communities to contamination. In: Aberg, B., and F. P. Hungate (eds.). 1967. Radioecological concentration processes. Proc. of an Intl. Symp., Stockholm, April, 1966. Pergamon Press. p. 897-912.

Paper describes observations on fallout Cs in river systems as well as Cs in tank experiments. Plant and sediment values given. Algae removed up

to 30% dose but soon after contamination activity was in sediment.
Notes CF comparisons only valid when samples have similar histories and ecologic conditions.

1969

105. Chamel, A., A. Fourcy and G. Pautou. 1969. Les Vegetaux Helophytes Detecteurs de Pollution Radioactive. In: Symposium International de Radioecologie, Centre d'Etudes Nucleaires de Cadarache France. p. 1083-1101.

Helophytes such as cattail, Phragmites, Iris and Phalaris are suggested as good pollution indicators for Cs, Co, Sr based on pond study experimental contamination. Leaf tissue was sampled because it was not in direct contact with contaminated water. CF values varied with time after contamination. Even though activity of water decreased dramatically with time, CF values increased with time. At 1 month post contamination, Phragmites leaf CF values were Cs=40-60; Co=100-110; Sr=14-22. All three tracers were fixed rapidly in roots.

106. Cline, J. F. 1969. The effects of substrate conditions on the uptake rate of Cs137 by plants. In: Symp. on Radioecol. Proc. of the Sec. Natl. Symp., 1967. D. J. Nelson and R. C. Evans (ed.). U.S. AEC Report CONF-670503. p. 547-552.

Experiments on the uptake of Cs137 by plants from different substrates are described. The degree of water saturation of a substrate strongly influences the availability, hence, uptake of Cs. Thus uptake by plants is solution culture > clay suspension > water saturated soil > irrigated soil. Uptake by rice grown in flooded containers was influenced by position of tracer placement in soil; surface placement resulted in 6-7 times uptake as uniform mixture in upper six inches of soil.

107. Crosley, D. A., Jr. 1969. Comparative movement of Ru106, Co60 and Cs137 in arthropod food chains. In: D. J. Nelson and R. C. Evans (ed.). Symp. on Radioecol. Proc. of the Sec. Natl. Symp., 1967. U.S. AEC Report CONF-670503. p. 687-695.

Results of sampling program at White Oak Lake disposal area after Ru106 seepage was discovered. Results illustrate the potential for Ru movement within ecosystem and suggest that it can become more concentrated than Cs137 in terminal links of food chains.

108. Harvey, R. S. 1969. Uptake and loss of radionuclides by the freshwater clam Lampsilis radiata (Gmel.). Health Phys. 17: 149-154.

Uptake of fission product wastes from fuel processing stream by small native clams was studied under natural conditions at SRP. Clams were exposed to effluent for 91 days then transferred to a nonradioactive stream. Only Sr and Cs were concentrated in shell. Soft tissue CF

were: Cs=220, Co=790, Ce=900. Ce was shortest and Co the longest biological half life (34 and 277 days respectively.)

109. IAEA. 1969. Environmental contamination by radioactive materials. Proc. of a seminar, Vienna, 1969, FAO, IAEA, WHO.

A recent review mostly concerned with fallout and food chains to man. Some basic reviews on plant uptake (incl. ^3H) and methods of analysis included. A good general review but not very specific in most cases. Only waste mgmt. info. is on reactor effluent discharge into rivers (Hanford situation) and waste disposal to the seas (Windscale situation).

110. Iskra, A. A., V. G. Vakhurov, and N. V. Kulikov. 1969. The role of freshwater vegetation in the migration and translocation of natural radioactive elements in a body of water. In: Symp. Intl. de Radioecol., Centre d'Etudes Nucleaires de Cadarache, France. p. 251-268.

Most of the fresh-water plants investigated are able to absorb uranium, radium and thorium from their aquatic environment. In water bodies with standing water, uranium and radium were found to possess a higher migratory ability than thorium. Uranium accumulates predominantly in the biomass of aquatic plants, thorium in detritus and ground, while radium is more or less evenly distributed among the components of the water basin. According to their ability to accumulate and to be accumulated, the radioactive elements investigated may be arranged in the following order: thorium > Radium > uranium, and the components of the water body in the order: detritus > plants > ground.

111. Kalnina, Z. K., G. G. Polikarpov and N. S. Risik. 1969. Concentration factors of strontium-90 and uranium of hydrobionts living in lakes of different types. In: Symp. Intl. de Radioecol., Centre d'Etudes Nucleaires de Cadarache, France, p. 233-248.

Most discussion on Sr and Sr-90, with some on U-238, and distribution in biota and sediments in eutrophic and dystrophic lakes. Difference in Sr were noted between lakes, between seasons, and between organisms. Dystrophic water contained more Sr, but macrophytes and sediments contained less than eutrophic lake counterparts. Planktonic organisms always highest; fall values tended higher than spring - summer for either type lake. CF given.

112. Koranda, J. J. 1969. Residual tritium at Sedan crater. In: Nelson, D. J. and R. C. Evans (eds.). Symp. Radioecol: Proc. of the Sec. Natl. Symp., 1967. U.S. AEC Report CONF-670503. p. 696-708.

Studies on a very simple ecosystem 2-2 1/2 years after the "Sedan" cratering experiment indicate that H^3 in soil water, plant tissue water, plant tissue bound water (food), and rodent tissue water is in near equilibrium. Transpiration water was about equal to soil water H^3 . Concluded that under low annual rainfall conditions, H^3 may be considered

one of the most biologically significant radionuclides in a detonation environment because of its rather complete involvement in all levels of the ecosystem.

113. Merlini, M. and R. Bittel. 1969. The uptake, loss, and distribution of radiocobalt in freshwater fish Lepomis gibbosus L. In: Symp. Intl. de Radioecol., Centre d'Etudes Nucleaires de Cadarache, France. p. 399-412.

Article describes and discusses results of short-term (up to about 1 month) exposure to Co58 tagged food and/or water for sunfish and goldfish. Conclusions - uptake is age-dependent, more rapid for small animals. Thus, making CF value assignments difficult CF's may reach >100 depending on exposure time and age. Activity (Co58) enters fish through food, or water (gills as well as swallowed water).

114. Reichle, D. E. and D. A. Crossley, Jr. 1969. Trophic level concentrations of cesium-137, sodium and potassium in forest arthropods. In: Nelson, D. J. and R. C. Evans (eds.). Proc. of the Sec. Natl. Symp., 1967, Symp. on Radioecol. U.S. AEC Report CONF-670503. p. 678-686.

Reports of a continuing study on cesium-137 - tagged Liriodendron forest cryptozoan community. Most Cs data reported earlier (See No. 77). Here add a few new species and data on Na and K. All saprovores spp. previously reported - additional predator data presented. Changing elemental content during litter decay (food), nutrient availability and assimilation efficiencies, and biological half-lives are all variables affecting absolute concentrations and Cs/K at each trophic level.

1970

115. Ophel, I. L. and C. D. Fraser. 1970. Calcium and strontium discrimination by aquatic plants. Ecol. 51: 324-327.

Nineteen vascular plants, one moss and two algae growing in Perch Lake were examined for their strontium contents (relative to calcium) and compared to lake water. Results expressed as ORs. Sixteen spp. enriched strontium relative to calcium. One spp. shows remarkable discrimination against strontium, four spp. show no discrimination.

116. Reichle, D. E., P. B. Dunaway and D. J. Nelson. 1970. Turnover and concentration of radionuclides in food chains. Nucl. Safety 11: 43-55.

An excellent review of current status of predictive ecological models tailored to the assessment of the environmental consequences of radioactive contamination. Major emphasis is on animal assimilation and turnover. More substantial information is required than now available because data of one ecosystem cannot be applied to another. For chronic release situations CF values often suffice for single source - pathway - receptor model.

117. Romney, E. H., H. H. Mork and K. H. Larson. 1970. Persistence of plutonium in soil. plants and small mammals. Health Physics 19: 487-491.

Periodic surveys over past 10 yrs. reported on HTS fallout Pu. Downward migration of particles into native soil noted as well as wind and water redistributions. Slow uptake by plants noted but increased with time (5 yrs). DTPA enhanced plant uptake of Pu. Inhalation important to native rodent uptake of Pu, but consistent high levels in GI tracts indicate ingestion also important.

1971

118. Garrett, A. R. Jr., S. L. Cummings and J. E. Regnier. 1971. Accumulation of Cs137 and Sr85 by Florida forages in a uniform environment. Health Physics 21: 67-70.

Study was conducted on uptake of Sr85 and Cs137 from same soil by eight forage grasses and Ladino clover. All spp. were noted to accumulate Sr or Cs in leaf tissue relative to soil levels of contamination. Clover was highest in both. Soil had low CEC, low Cs fixing capacity, and high percent sand. These soil properties explain greater uptake of Cs than of Sr from this unique soil.

119. Ophel, I. L. and C. D. Fraser. 1971. The fate of Cobalt-60 in a natural freshwater ecosystem. Presented at Third Natl. Symp. on Radioecol., Oak Ridge, Tenn. May 10-12, 1971.

The behavior of Cobalt-60 in a freshwater lake was studied over a two year period. Activity was in solution or associated with particles <1.2 μ m in size. A material balance showed that the lake as a 30% retention capacity for Cobalt-60 and that >90% of the activity was in the sediments (0-30 cm depth). In general, DF decreased up food chain from aquatic plants. Best estimate of food web CF are presented.

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