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RESIDUAL TRITIUM AT SEDAN CRATER

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April 2, 1967

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RESIDUAL TRITIUM AT SEDAN CRATER¹

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ABSTRACT

Residual tritium from the Sedan thermonuclear detonation, 6 July 1962, was scavenged by or entrained in the 5-6 million tons of earth materials moved by the detonation. As a result, the Sedan post-shot environment contained a most significant biological tracer in the form of THO. Residual tritium (THO) is found in μCi concentrations in the interstitial water of the Sedan throwout soil, and in the loose tissue water of plants which have re-invaded the new substratum deposited on the landscape adjacent to the crater. Tritium is present not only in the loose tissue water of vascular plants growing on the Sedan throwout, but a comparable level is also found in the tissue-bound hydrogen of these plants. Herbivores, mainly heteromyid rodents, which have re-invaded the Sedan post-shot environment and reside there, also have tritium concentrations in their body water between 1 and 3 $\mu\text{Ci}/\text{ml}$. These body-water tritium concentrations are closely related to the levels of tritium in the plant tissue-bound hydrogen. Soil-water tritium concentrations in the soil air at the rodent burrow depth are several orders of magnitude lower than the observed

¹This work was performed under the auspices of the United States Atomic Energy Commission.

body-water level. The inspirational route of entry of tritium into the animal is therefore assumed to be a secondary one, with the primary source being the plant organic matter synthesized in the Sedan post-shot environment which is used as the animal's food base.

The internal dose to the resident mammal at Sedan Crater from residual tritium is estimated to be between 18 and 268 rad, or about 10 times that from external radiation sources resulting from the detonation.

INTRODUCTION

On July 6, 1962, the 100-kt Sedan thermonuclear detonation produced the largest excavation created by a single man-made explosive device. This cratering event, part of the Atomic Energy Commission's Plowshare Program for the development of industrial and civil application of nuclear explosives, is described in detail by Nordyke and Williamson (7), and specific details may be sought in the large number of reports on the Sedan event issued by the Peaceful Nuclear Energy Branch of the Atomic Energy Commission.

From an ecological standpoint, the Sedan event is without a doubt one of the largest terrestrial tracer experiments ever conducted. Not only were multiple radioactive "tags," in the form of fission and activation products, dispersed throughout the 5-6 million tons of excavated earth deposited on the landscape adjacent to ground zero, but also a very significant biological tracer was injected into this mass of earth, namely, residual tritium in the form of THO, tritiated water. As a result of this large scale earth-moving event, a new substratum became available to the local biotic and climatic forces — one in which many radioactive elements occurred, and one in which the basic life compound, water, was also labelled. Figure 1 is an aerial photograph of Sedan crater and the throwout area a short time after the detonation.

It was in this ecological context that the study of residual tritium at Sedan crater was begun in January, 1965, two and one-half years after the event. It should not be assumed from the previous remarks that the ecological considerations discussed above were included in the main purpose of the Sedan event. The Sedan experiment was primarily concerned

with cratering phenomena in the 100-kt range of yields and with the nature of safety problems associated with cratering detonations. Perhaps some ecological effects could be included in the latter.

Scientists of the Plowshare Division of this Laboratory estimated that residual tritium from the Sedan event was of the order of 10^6 curies of tritium per 100 kt of fusion yield (6). This residual tritium was converted to THO in the detonation and scavenged, or entrained, by the lofted excavated materials as they fell back into the crater or onto the adjacent terrain as throwout and base surge.

In the summer of 1964, Plowshare Division scientists drilled into the fallback in Sedan crater at ground zero, and collected samples of the earth materials. The average concentration of tritium in the first 300 ft of fallback in the crater to the point of emplacement of the device was $0.36 \mu\text{Ci/gm}$ of soil material. The adsorbed water content of this soil was given as 6%, which would produce a concentration of $5.97 \mu\text{Ci/ml}$ of soil water (or 1.85×10^9 T. U.). It was assumed by the Plowshare scientists that similar concentrations would pertain on the crater lip and close-in throwout. These were the available data on residual tritium at Sedan crater when the present study began. The data of Knox (6) are shown in Figure 2.

The concentrations of tritium reported here were determined in water samples obtained by freeze-drying soil, fresh-frozen plants, or frozen animals. The water extracted in this manner is referred to as loose water and will be compared or related to tissue-bound water in the plants, or mineral-bound water in soils. The mineral- and tissue-bound hydrogen and tritium are obtained by combustion of the sample, which in most cases

was previously freeze-dried or in the case of plants, field-cured. Most of the water samples obtained from the Sedan area can be assayed easily by conventional liquid-scintillation counting techniques. Background samples are usually gas-counted, or electrolytically enriched to obtain an accurate count in the region below 72 dpm/ml or 10^4 T. U. A tritium unit (T. U.) is defined as the ratio of one tritium atom per 10^{18} hydrogen atoms, or 3.23×10^{-3} pCi/ml. The tritium unit is widely used in fallout studies of worldwide precipitation, and is also useful to the biologist because it is an expression of specific activity.

In January 1965, soil and field-cured plant samples (mainly Russian thistle, Salsola kali) were collected along two transects of the Sedan crater lip and throwout. The aim of these first collections was twofold: first to determine if tritium was present on the crater lip and the throwout in concentrations comparable to those found in 1964 at ground zero in the crater, and second to investigate the biological significance of those concentrations to plant and animal organisms that had reinvaded the Sedan postshot environment. The January 1965 plant samples represent the accumulation of tissue-bound tritium attained during the entire 1964 growing season, because the Russian thistle is an annual. The soil data indicate the levels of soil-water tritium in January, 1965, the time of sampling. Because most of the annual precipitation occurs during the winter, it is to be expected that tritium concentrations in the superficial soil strata will be diluted to some extent by rainfall of lower specific activity. In 1963 Rickard and Murdock (11) found maximum penetration of rainfall at a depth of 6 decimeters (approximately 24 inches) in the northern portion of Yucca Flat.

Figure 3 shows the tritium concentrations in loose or capillary soil water and in mineral-bound soil water from the January 1965 samples collected at Sedan crater. A series of samples were collected from the crater lip along two transect lines to a distance of 4000 ft from ground zero. The maximum concentrations at one foot depths are lower than the 1964 data (6), but at a depth of three feet on the crater lip (20A), a value in excess of 10^9 T. U. approximates the 1964 concentrations for the crater fallback (6). The concentration of tritium in soil water decreases with distance from the crater in both of the January 1965 transects of the throwout, and this slope of concentration with distance is apparent in most of the other data presented here. The relationship between capillary (and hygroscopic) soil water and the mineral-bound tritium (as defined above) is not completely clear at this time, and experimentation is presently in progress to elucidate this pertinent area of study.

The closer correlation between mineral-bound tritium and capillary-water tritium at the crater lip in contrast to that seen at 4000 feet, is probably related to the composition of the throwout at those points. The crater lip materials are those that were moved in mass and the depth is great, whereas the substratum at 4000 ft is composed of the preshot native soil surface with a shallow overlying deposit of base surge and fine throwout materials. The percolation of such fine materials into an undisturbed soil surface of the desert may occur, but this probably does not take place in any significant amounts. However, it may be possible for tritium to be eluted into the subsurface soil strata from a surficial deposit of base surge materials.

The tissue-bound tritium concentrations in field-cured plant samples that matured in 1964 are shown in Fig. 4. These values approximate those

shown in Fig. 2 for loose soil-water tritium, although the two kinds of data are not directly related. Cline (5) reported that less than 1% of the tritium activity in the root solution occurred as tissue-bound tritium in bean plants after 70 hours of exposure. One would expect a greater saturation of the hydrogen compartments in plant tissues by tritium when the exposure period spanned the entire growth period as in the plant tissues synthesized at Sedan crater. In soybean plants grown to maturity (from seed to seed) in tritiated nutrient solution, Chorney and Scully (4) found the following concentrations of tritium in the plant tissues:

	Constituent water [*] μCi/ml	Tissue water μCi/ g H
Leaves	37.2	
Stems	38.9	337.8
Roots	37.5	
Nutrient solution	37.5	

^{*}If constituent water is expressed on a gram hydrogen basis (as can be done by multiplying the values in the first column by 9), it is seen to be in equilibrium with the tissue hydrogen concentration.

From the data of Chorney and Scully, it appears that if an herbaceous plant is exposed to tritiated water during its entire growth period, an essentially equilibrium condition is established between loose or constituent tissue water, tissue-bound hydrogen, and water taken up from the root zone, if steady-state conditions prevail as in their study. In an open system, as in nature, stable hydrogen may enter the plant through the aerial portions of the plant, because water is exchanged in both directions between the plant and the atmosphere. The demonstrations by Aronoff

and Choi (2) and others of the introduction of THO into the leaves of a plant as vapor is adequate demonstration of this phenomenon. In addition, stable hydrogen is "inherited" by the plant from seed materials that were synthesized in a non-tritiated environment. The degree of mobility of hydrogen compartments in plant tissues is not well known; such knowledge would certainly be useful in determining whether or not those compartments would completely equilibrate with the specific activity of the nutrient during a single life cycle exposure.

The data from the analysis of the January 1965 samples indicate that residual tritium is present in the Sedan throwout materials at levels up to 6 orders of magnitude higher than the environmental water tritium background. In Southern Nevada during this time, tritium concentrations in rainfall were in the range of 1000-1400 T. U. The maximum concentrations of tritium in soil water at a depth of three feet on the crater lip do not differ greatly from those determined by Plowshare scientists in 1964. Concentrations decrease with distance from the crater with values at 4000 ft from one to two orders of magnitude above the tritium background of the local environmental water at the time.

More significant biologically, however, is the high level of tissue-bound tritium present in plants that grew on Sedan throwout in 1964. If typical ecological relationships pertain in the postshot Sedan environment, it is reasonable to expect that residual tritium from the Sedan event will be found in other trophic levels in that ecosystem if the basic autotrophic organisms are being affected to this extent. This hypothesis is borne out in the analytical data.

The ecosystem that has developed on the Sedan throwout substratum as the result of natural biotic phenomena is a relatively simple one. The primary plant invader is the annual herb, the Russian thistle (Salsola kali L.) which has formed almost continuous stands at distances of 1000 ft to 2500 ft from ground zero. Separate clumps are characteristic on the crater lip and out to 1000 ft. The wind has moved and concentrated fine soil particles on the postshot topography and these local concentrations of fine materials to some extent have determined the distribution of plant individuals or clumps. A few individual plants of Astragalus lentiginosus were seen at the north edge of the crater within 200 ft of the crater lip in 1965, and several shrubs of Atriplex canescens were found between 800 ft and 2000 ft during the summer of 1965.

The only mammals that have been found to live exclusively on the Sedan throwout are the kangaroo rat, Dipodomys merriami, and a deermouse, Peromyscus maniculatus. Signs of a predator, probably a fox, are abundant. Small flocks of horned lark are seen frequently in the Sedan area but these birds may forage outside of the area of interest. Two species of ground beetle are abundant on the Sedan throwout and appear in large numbers in the spring and fall; these are Eleodes armata and Edrotes orbis, which apparently forage on vegetal debris found on the ground. Since they utilize the same food base as the mammals in the area, collections of these insects were made for tritium assay.

In May, 1965, when the growth of the desert vegetation was near its peak, a second, more detailed sampling of the Sedan environment was made. Green, growing plants, mainly seedlings of Salsola kali, were collected along four

transects of the crater lip and throwout zone to a distance of 4000 ft from ground zero. Soil was sampled at depths of one and three feet at the same sites where growing plants were collected.

The tritium concentrations in loose or capillary soil water, shown in Fig. 5, indicate increasing concentration both with depth and with proximity to the crater. At 2000 ft from ground zero, and some concentrations were equivalent to those at the crater lip, probably because throwout from the crater lip to 2000 ft was all moved in mass.

The loose tissue-water tritium concentrations in plants shown in Fig. 6, in general are intermediate between the tritium concentrations of soil water at one and at three feet. This may be interpreted as evidence that these plants are utilizing water from the soil stratum between one and three feet at this time. Three other plant species in addition to the Russian thistle were collected near the outer edge of the throwout zone at 3500 ft from ground zero. The values for loose tissue water in these species were also in the same range for those in the Russian thistle at comparable distances from the crater. It appears that the tritium concentrations in the loose water of plants growing on Sedan throwout are the product of a widespread environmental phenomenon and not caused by unique morphological or physiological characteristics of a single species.

In Fig. 7, the January 1965 (1964 growing season) tissue-bound tritium concentrations in plants are compared to those obtained in May 1965. The order-of-magnitude difference may be related to the difference in the ages of the plant samples at the time of collection. The May plants were mostly seedlings, not more than 3-4 inches tall, while the January plants were mature individuals that had dried or field-cured in the exact place where they grew. Young,

meristematic tissues have small vacuoles and a lower water content; the water content of older Russian thistle, 10-12 inches tall, is over 90% of the fresh weight while that of the seedlings was 60-70%. Such physiological factors may influence the rate at which plant shoot tissues attain an approximate equilibrium with the soil water tritium concentrations.

Complete equilibration between the loose tissue-water in shoots and the water of the soil (or root zone) is not expected because of the possible movement of lower specific activity water from the atmosphere into the shoot tissues. This tends to be a source of dilution of loose tissue-water tritium, according to Cline (5) and Raney and Vaadia (9), but would be less important in the desert where the water content of the air during the summer is usually low. Raney (8) demonstrated that when pre-dried air was supplied to the plant, tissue-water tritium concentrations in shoots were almost completely equilibrated (98%) with those in the root zone.

If the true significance of the data is to be realized, it is necessary to relate the residual tritium levels at Sedan crater to a suitable background condition. In Fig. 8, water samples collected in other parts of the Nevada Test Site are compared with two from the Sedan area at 4000 ft from ground zero. These background values illustrate the merging of the local tritium background with those existing in the Sedan crater area. The background tritium concentrations are the result of worldwide fallout produced in past atmospheric tests. World precipitation is gradually returning to the levels seen before the thermonuclear test period, which over continents were in the range of 10-15 T. U., according to Thatcher et al. (13).

Incoming precipitation (snow or rain) was generally above 1000 T. U. during this period. It is interesting to note that the tritium content of deep ground water from wells at the Nevada Test Site, from 2000 to 3000 foot depths, is an order of magnitude less than recent meteoric water. The tritium content of this water is no doubt affected by radiological decay during long underground storage as well as by the variation that has occurred in the tritium content of precipitation since the period of nuclear testing.

Thus the maximum concentrations of tritium at Sedan crater are as much as six orders of magnitude above the environmental water tritium background, and these local, high concentrations are reflected in soil water, in the loose tissue-water of plants, and in the tissue-bound hydrogen of plants growing on Sedan throwout. A near-equilibration of the water compartments in the soil, where the THO was initially injected by detonation, with the biological water and hydrogen compartments of the organisms that have reinvaded the Sedan throwout substratum is apparent.

Since vascular plants utilize less than 1% of the water absorbed by the root system for growth processes, and release large amounts to the atmosphere in transpiration, it was expected that elevated concentrations of tritium would be present in the transpired water released by the aerial portions of plants growing on Sedan throwout. Plastic bags were taped around branches of plants growing in the Sedan area during the summer of 1965 at various distance from ground zero. The Russian thistle is not the most desirable plant for this technique, because the apiculations at the end of each leaflet lacerate the bags as the plant moves in the wind, usually disrupting the conditions favorable for vapor condensation. Transpirational water is easily

trapped and retrieved by this method, which was used by Woods and O' Neal (15); however the rate of transpiration is no doubt enhanced by the micro-climate created around the transpiring plant parts in the bag. Tritium concentrations in transpirational water, shown in Fig. 9, indicate increasing concentration with proximity to the crater. If it were not possible to obtain a soil water sample, transpirational water would provide a good approximation of the tritium content of the soil water. Where 3.88×10^8 T. U. were present in transpirational water of Salsola kali, the tissue water (obtained by lyophilization) contained 3.96×10^8 T. U.

The amounts of water released to the atmosphere by plants in transpiration are considerable, and under the conditions observed at Sedan crater, it is possible that this water, containing a high concentration of tritium, could have produced an elevated concentration in local surface air. In August 1965, a brief convectional shower occurred at Sedan crater during the collection of field samples. A clean plastic tray, which had previously been sealed in a plastic bag, was placed on the roof of a truck and rain water was collected at a height of approximately seven feet. The tritium concentration in this water was more than 10^5 T. U., while in rain water received at other locations on the same day, it was only 300-400 T. U. It is possible that the wetting of the hot surface of the Sedan throwout soil resulted in production of water vapor with an increased tritium content. An alternative explanation is that transpirational THO may have produced elevated tritium concentrations in the surface air, from which tritium was scavenged by the rain.

Because residual tritium as THO is intimately involved in plant metabolism and in the synthesis of organic matter, as the loose tissue-water and tissue-bound hydrogen tritium concentrations indicate, related effects are

to be expected in the resident herbivorous mammals utilizing these plants as a food base. At least two species of rodents had reinvaded the Sedan throwout area by 1965; they are apparently subsisting on the Russian thistle which composes the bulk of the vegetation on the crater lip and out to a distance of 2800-3000 ft. Population studies of desert rodents by Allred and Beck (1) in Yucca Flat indicate a home range of 400-500 ft for the species of animals found at Sedan crater. It is reasonable to assume, therefore, that the entire food supply of an animal living anywhere from the crater lip to 3000 ft has been obtained from vegetation growing on Sedan throwout materials.

In October 1965, a sample of 24 animals was live-trapped within 100 yards on two sides of Sedan crater. Most of the animals were kangaroo rats (Dipodomys merriami) and the remainder were deermice (Peromyscus maniculatus). Organs were taken from the freshly killed animals and the carcasses were frozen immediately in dry ice. The body water of these animals was extracted by freeze-drying and tritium concentrations were determined by liquid scintillation counting techniques.

Tritium concentrations in the body water of the Sedan area animals are given in Fig. 10 in T. U. and in μCi per milliliter of water. The body-water volumes retrieved from the vacuum traps ranges from 58 to 70% of the fresh body weights, which is in good agreement with the values reported by Schmidt-Neilsen and Schmidt-Neilsen (12) for the same species. If the tissue-bound tritium concentrations in plants growing at the crater lip (in Fig. 7) are compared to the body-water concentrations, it is obvious that the two kinds of data are closely related.

The body-water tritium concentrations shown in Fig. 10 may be attributed to two sources of tritium in the Sedan environment and to two

physiological routes of entry into the mammal. The soil water has been shown to contain tritium concentrations of over 10^5 T. U. at a depth of one foot, where most burrows occur. The vegetation that provides the food also contains even higher concentrations of tritium as loose tissue water and as tissue-bound tritium. In addition, the kangaroo rat often seals the entrance to its burrow in the daytime. The result is a tendency for retention of soil moisture and its constituent tritium; thus these animals could conceivably acquire part of their tritium burden via inspiration.

One value from the October animal data, that of more than 10^7 T. U. for the ground beetles, casts some suspicion on the inspirational route. The beetles do not live in deep burrows at the depths where tritium concentrations in the soil water (and soil air) are comparable to those observed in their body fluids, which are essentially in the same range as those in animals that spend at least half of their lives underground. Their tritium burdens must be derived from their food base, which is the same as for the mammals.

To determine whether the soil air or the food base is most effective in causing the observed tritium burdens in small mammals in residence on Sedan throwout, one must consider the various environmental factors that could change those possible sources. The concentrations of tissue-bound tritium in field-cured plant tissues did not change appreciably from 1964 to 1965. The variation has been from 4.0×10^8 T. U. to 1.0×10^9 T. U. during this period for plants growing from the crater lip out to 500 ft. Although the tritium content of young, green plant tissues synthesized early in the season when the soil water reflects some dilution by winter rainfall will differ from that of mature plants, it is probably quite constant in the diet of the kangaroo rat, which

is primarily a seed eater. Therefore one can assume an almost constant level of tissue-bound tritium in the plant food base.

Dilution by rainfall is the most obvious environmental factor that would reduce the tritium concentrations in the soil water (and soil air) at Sedan crater, and within the appropriate biological half-life, the tritium concentrations in the body water of mammals breathing that air. The rainfall received at Sedan crater since the shot date is shown in Fig. 11. Fall and winter rainfall is characteristic of the desert climate at the Nevada Test Site. During late 1965, a record rainfall of 10.8 inches occurred, with over 5 inches in late October, December, and January 1966. Soil moisture data indicate that rain had penetrated to 36 inches in January, 1966, as compared to the usual 24 inches under normal rainfall conditions, as reported by Rickard and Murdock (11). If the inspirational route is significant, then soil-water and animal body-water tritium concentrations should reflect the dilution caused by this unusual amount of rainfall.

To investigate these interrelationships, samples of soil and animals were obtained in the Sedan crater area during early 1966. A small sample of six animals was obtained in early February; their body-water tritium concentrations are shown in Fig. 12, compared with data obtained in October from animals trapped in the same area. The rainfall that occurred in the interim between these two samples is also shown. It is obvious that the February body-water concentrations are all in the same range as the October values.

The assumption that the THO concentration in soil water can be lowered by rainfall received at Sedan crater is supported by the data from a single

sampling station during the period of high rain and earlier in 1965 (Fig. 13). The tritium concentrations at one foot reflect the effectiveness of rainfall dilution on soil-water THO. In January 1965 the one-foot concentration was high, in May 1965 it was diluted by the 2.4 inches of rain received in April, when evaporation had not reached the summer maximum, and by August the concentration was again close to the January level. By December, when 5 inches or more rain had fallen in the area, the soil-water THO concentration at one foot was considerably diluted; in February 1966 it reached the minimum value that has been recorded at this sampling station. It is apparent also from Fig. 13 that soil THO concentrations at three feet were not affected until February, when they dropped almost an order of magnitude in response to this unusual rainfall.

Most of the burrows of the small mammals at Sedan crater are within one foot of the surface. By February 1966 the soil-water tritium concentrations in this stratum had been lowered by two orders of magnitude from the August level. If the half-life of tritium in the body water of the kangaroo rat is short enough, it should reflect this lowering of soil-water tritium. According to Thompson (14), the half-life of tritium in the body water of mice is 1.1 days, but in the kangaroo rat because of its unique water metabolism, the half-life is expected to be much longer.

The water metabolism of the kangaroo rat has been described in a classic work by Schmidt-Neilsen and Schmidt-Neilsen (12) on the water balance of desert animals. The kangaroo rat not only has evolved a specialized behavior to enable them to survive in an arid environment, but it also possesses unique physiological and anatomical characteristics. These features enable the animal

to derive most of its water requirements from the food intake, which is mainly dry, and provide for extremely economical use of the water derived from the animal's own metabolic processes. The kangaroo rat can maintain a positive water balance on dry food alone, without ingesting any free water, as long as the humidity does not fall below a critical level.

The half-life of the body water in Dipodomys merriami can be estimated from the mean body-water volume of the Sedan animals, 23.3 ml (N = 18), assuming an average food intake of 2.5 g/day, which upon oxidation yields 1.34 ml of water (12). Applying these values in the following formula

$$T_{\frac{1}{2}} \text{ body water} = \frac{\text{Body water volume}}{\text{Daily water intake}} \times 0.693$$

one obtains a value of 12-13 days for the half-life. The value of 1.34 ml of water yield for 2.5 g of pearled barley was determined by Schmidt-Neilsen and Schmidt-Neilsen (12) in laboratory studies of D. merriami. Combustion data on Russian thistle tissues indicate a lower yield of water, between 40 and 50% of the dry weight. Richmond et al. (10) found a mean body-water content of 62.37% of the fresh body weight in their study of the water metabolism of Dipodomys deserti, a larger species of kangaroo rat. With the tritium dilution method, they determined a 10-15 day half-life for body water in D. deserti, which is in agreement with our estimation. Recent studies in our laboratory with two samples of animals from the Sedan area indicate that a 13-15 day half-life is quite reasonable.

Thus if inspiration was the most significant route, there was time between October 1965 and February 1966 for the body-water tritium concentrations to respond to lower levels created in the soil air. If body-water tritium

concentrations equilibrated with the soil air within the appropriate time interval, they would have been two orders of magnitude lower in February, 1966 than in October 1965.

But the body-water tritium concentrations were not lowered during a period of unusually high rainfall that did affect the soil-water tritium concentrations. It is concluded therefore that the observed body-water tritium burdens in the mammals at Sedan crater are due primarily to the ingestion of plant organic matter that has acquired a high specific activity of tritium during growth processes by utilizing soil water containing a high concentration of THO. The biological processes by which this high specific activity of tritium was acquired are common to all natural ecosystems. However, in any ecosystem that was very different from Sedan crater, the specific environmental factors unquestionably would interact to produce a different pattern of tritium movement in the ecosystem.

It is of interest to determine the radiobiological significance of the body water-concentrations of tritium in the small mammals at Sedan crater. The tritium concentrations ranged from 0.17 to 2.56 $\mu\text{Ci/ml}$. The calculated dose rate to the animals from body-water tritium only, utilizing constants given by Brunner (3), is from 2.07 to 30.7 mr/hr. The annual dose to the animal from body-water tritium is from 18 to 268 rads. If a relative biological effectiveness of 1.7 is applied, the values are increased to 30.6 and 455.6 rem/year. The same animal received from the external beta-gamma dose rate at a depth of one foot in the soil a dose of 3-4 mr/hr, or approximately 26 rad/year. The significance of residual tritium to these animals, whatever its mode of entry, is obvious from the above estimates of yearly radiation dose from various sources. In the particular ecological system at Sedan crater, residual

tritium has produced an internal radiation dose to mammals which is approximately ten times that received from external beta-gamma radiation.

In other climatic regions where the flux of precipitation is greater, residual tritium in earth materials moved by a thermonuclear detonation may be effectively eluted from the soil and diluted in all levels of the soil-plant-animal ecosystem. The response of soil-water tritium at Sedan crater to a modest additional increment of rainfall received in late 1965-1966 is given as evidence of this possible effect. In an environment of low annual rainfall, residual tritium may be considered one of the most biologically significant types of radioactivity remaining in the detonation environment, primarily because of its complete involvement in all levels of the ecosystem.

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FIGURE CAPTIONS

- Figure 1. Aerial photograph of Sedan crater and its throwout area.
- Figure 2. Residual tritium concentrations in Sedan crater fallback, 1964.
- Figure 3. Soil-water tritium concentrations in Sedan crater and throwout area, January 1965.
- Figure 4. Tissue-water tritium concentrations in Russian thistle, 1964 growing season.
- Figure 5. Soil-water tritium concentrations in Sedan crater and throwout area, May 1965.
- Figure 6. Loose plant-tissue-water tritium concentrations in Sedan crater area, May 1965.
- Figure 7. Tissue-bound tritium concentrations in Russian thistle, Sedan crater area.
- Figure 8. Tritium concentrations in loose soil water, rain, snow, and well water, in control areas, Nevada Test Site.
- Figure 9. Tritium concentrations in plant transpiration water, Sedan throwout area, 1965.
- Figure 10. Tritium concentrations in the body water of small mammals and insects, Sedan crater area, October 1965.
- Figure 11. Rainfall since Sedan detonation (July 1962), BJY Station, U. S. W. B. S.
- Figure 12. Tritium concentrations in body water of small mammals, Sedan crater area, October 1965 - February 1966.
- Figure 13. Soil-water tritium concentration as a function of depth, January 1965 - February 1966.

Koranda - Fig. 1

Koranda - Fig. 2

Koranda - Fig. 3

Koranda - Fig. 4

Koranda - Fig. 5

Koranda - Fig. 6

Koranda - Fig. 7

Koranda - Fig. 8

TRITIUM IN PLANT TRANSPIRATION— SEDAN THROWOUT, 1965

T. U.

10^8

.323
 $\mu\text{Ci/ml}$

10^7

.032
 $\mu\text{Ci/ml}$

10^6

.003
 $\mu\text{Ci/ml}$

10^5

CONTROL PLANTS DURING SAME PERIOD—1050 T.U.
OR IN EQUILIBRIUM WITH RAINFALL TRITIUM

CRATER

1000'

2000'

3000'

4000'

DISTANCE FROM SEDAN G.Z.

Koranda - Fig. 9

Koranda - Fig. 10

Koranda - Fig. 11

Koranda - Fig. 12

Koranda - Fig. 13

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