INTRODUCTION

New ecological problems may arise in local areas as the level of radiation in the biosphere increases. We must know the radiation doses that are critical to the survival of tree seed and seedlings before we can predict with any certainty the long-range ecological effects of radiation in forested areas.

The seed radiosensitivity of 18 tree species native to the Eastern Deciduous Forest varies from species to species (Heaslip, 1959). The seed of many of these species ripens in the fall but does not germinate until embryo dormancy is broken by low winter temperatures. The radiosensitivity of seed of seven tested species increases when dormancy is broken (Heaslip, 1959). Radiosensitivity is not constant but varies with water content, rate of physiological activity, and numerous other related factors (Nilan, 1956). The effect of factors affecting seed and seedling radiosensitivity must be learned if we are to make a strong ecological approach to the problem of survival and continuation of forest communities in areas subjected to increased levels of radiation. In the present paper, I will consider the effects of physiological activity on seed and seedling radiosensitivity, and compare the relative roles of water and physiological activity on seed radiosensitivity.

Early workers said seed radiosensitivity increased directly with the water content (Gustafsson, 1947). Kozak (1955, 1957), Caldecott (1954, 1955a, 1955b), and Ivanoff (1956) have since noted an inverse relationship between seed water content and radiosensitivity. These latter workers used non-germinating crop seed as dormant seed in their tests of the relative role played by water in radiosensitivity. Using seed of native species with dormant embryos, I was able to test the effect of increased water content on the radiosensitivity of both dormant and physiologically active seed of the same species.

Sparrow and Christensen (1953) reported that the tolerance of plants to gamma radiation varies from species to species. Since seedlings are difficult to transplant and transport without injuries, seed radiosensitivity is more easily determined than seedling radiosensitivity. In the fall of 1959 I started a seedling irradiation project to determine the possibility of using seed radiosensitivity as an indirect test of seedling radiosensitivity.

PROCEDURE

Juglans nigra L., Quercus velutina Lam., and Q. alba L. seed samples were each collected from a single tree or group of trees in the same area to reduce the effects of genetic variability. Seed samples soaked in water for 48 hours and non-soaked seed samples of each species were irradiated with gamma rays from a cobalt-60 source at the University of Tennessee-Atomic Energy Commission Agricultural Research Laboratory in Oak Ridge, Tennessee. On the basis of previous experiments, seed samples were irradiated at the following air doses measured in thousands of roentgens:

<table>
<thead>
<tr>
<th>Species</th>
<th>0</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Juglans nigra L.</td>
<td>0</td>
<td>5</td>
<td>10</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>Quercus alba L.</td>
<td>0</td>
<td>3</td>
<td>5</td>
<td>7</td>
<td>10</td>
</tr>
<tr>
<td>Q. velutina Lam.</td>
<td>0</td>
<td>7</td>
<td>10</td>
<td>15</td>
<td></td>
</tr>
</tbody>
</table>

Seed water content at the time of irradiation was determined by drying a representative seed sample at 100° centigrade for 48 hours. The per cent water was calculated on the basis of total wet weight.

Seeds were planted in a one-to-one mixture of sand and sphagnum moss in an artificially illuminated laboratory. Quercus alba L. seed was planted as soon as possible after irradiation, for the roots began to emerge before irradiation even though the seed was stored at 0° to 5° centigrade. Juglans nigra L. and Quercus velutina Lam. seed was not planted until embryo dormancy was broken by stratifying the seed in moist sphagnum moss at 0° to 5° centigrade for 120 and 60 days, respectively. A third seed sample of each of these latter two species was irradiated at the close of the dormant period. Seed germination and seedling survival were used as a measure of radiosensitivity.

Liquidambar styraciflua L., Quercus velutina Lam., and Q. alba L. seedlings were used in seedling radiosensitivity tests because the seed of these species vary in radiosensitivity from slight to great. Year-old field seedlings of Quercus alba L., Q. velutina Lam., and Liquidambar styraciflua L., grown from seed collected from the same source as that used for seed irradiation studies were dug; the roots were placed in moist sphagnum moss in a polyethylene bag, and the entire plant was irradiated with 0, 3,000, 5,000, and 10,000 roentgens of gamma rays at the University of Tennessee-Atomic Energy Commission Agricultural Research Laboratory. Seedlings of each species were irradiated in the fall after the buds matured and in the spring as the buds opened (Table 1).

Table 1. Number of seedlings in the control and number at each of the three levels of radiations: 3,000, 5,000, and 10,000 roentgens.

<table>
<thead>
<tr>
<th>Species</th>
<th>November</th>
<th>December</th>
<th>May</th>
<th>May 1961</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quercus alba L.</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Q. velutina Lam.</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Liquidambar styraciflua L.</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>3</td>
</tr>
</tbody>
</table>

A statistical analysis of the data of the seed tests described above was made with an analysis of variance.

RESULTS

The data and results of statistical tests are presented in Tables 2 through 9. Throughout this discussion the expression "significant" is used to imply statistical significance at the .05 or .01 level of significance.

The average per cent germination of four test plantings of 50 non-soaked dormant Quercus velutina L. seed containing 30.81 per cent water did not differ significantly from that of four test plantings of 50 soaked dormant Q. velutina L. seed containing 37.61 per cent water (Table 4). Differences in the average per cent germination at the various levels of radiation were significant. There was a significant decline in germination as the level of radiation increased. There was no significant deviation from a linear response. The interaction of moisture and levels was significant. Consequently, it is concluded that the effect of radiation is dependent on water level even though
Table 2. Effect of gamma radiations on per cent germination of tree seed.

<table>
<thead>
<tr>
<th>Species</th>
<th>Seed Number per test</th>
<th>Per cent water</th>
<th>0</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dormant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quercus</td>
<td>50</td>
<td>4</td>
<td>30.81</td>
<td>84.5± 5.91</td>
<td>80± 7.6</td>
<td>78.5±10.8</td>
<td>43± 9.4</td>
<td>41.5±4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>velutina</td>
<td>Lam.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q. velutina</td>
<td>50</td>
<td>4</td>
<td>37.61</td>
<td>86± 6.5</td>
<td>63± 8.2</td>
<td>87± 3.6</td>
<td>73.5±8.1</td>
<td>61.5±6.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lam.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Juglans</td>
<td>25</td>
<td>4</td>
<td>19.08</td>
<td>60±10.9</td>
<td>82± 6.0</td>
<td>59± 3.4</td>
<td>38± 6.6</td>
<td>28±4.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>nigra L.</td>
<td>25</td>
<td>4</td>
<td>25.19</td>
<td>47±15.0</td>
<td>78± 8.9</td>
<td>41±12.2</td>
<td>73± 4.4</td>
<td>51±4.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. nigra L.</td>
<td></td>
<td></td>
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<tr>
<td>Active</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quercus</td>
<td>50</td>
<td>2</td>
<td>40.96</td>
<td>52±24.0</td>
<td>54±16.0</td>
<td>22±6.0</td>
<td>6± 2.0</td>
<td>5±3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>velutina</td>
<td>Lam.</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q. alba L.</td>
<td>50</td>
<td>3</td>
<td>44.45</td>
<td>90.6± 5.8</td>
<td>72±6.3.5</td>
<td>33.3± 7.5</td>
<td>48± 6.9</td>
<td>6.6± 2.4</td>
<td></td>
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</tr>
<tr>
<td>Q. alba L.</td>
<td>50</td>
<td>2</td>
<td>49.40</td>
<td>66± 6.0</td>
<td>17±2.0</td>
<td>45± 5.0</td>
<td>14± 4.0</td>
<td>5±3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J. nigra L.</td>
<td>25</td>
<td>2</td>
<td>28.35</td>
<td>60± 6.0</td>
<td>72± 8.0</td>
<td>78± 6.0</td>
<td>10±10.0</td>
<td>8±4.0</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1Average per cent germination ± one standard error of the mean, the latter being computed from the observations used to compute the average.

Table 3. Effect of gamma radiations on per cent survival of tree seed.

<table>
<thead>
<tr>
<th>Species</th>
<th>Seed Number per test</th>
<th>Per cent water</th>
<th>0</th>
<th>3</th>
<th>5</th>
<th>7</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>30</th>
</tr>
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<td>Dormant</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quercus</td>
<td>50</td>
<td>4</td>
<td>39.81</td>
<td>81± 5.3</td>
<td>77.5± 6.5</td>
<td>76.5±10.1</td>
<td>42± 9.0</td>
<td>40.5±4.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>velutina</td>
<td>Lam.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q. velutina</td>
<td>50</td>
<td>4</td>
<td>37.61</td>
<td>85.5± 6.4</td>
<td>61± 7.5</td>
<td>86± 4.2</td>
<td>73±7.7</td>
<td>60±6.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lam.</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Juglans</td>
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<td>4</td>
<td>19.08</td>
<td>42± 6.8</td>
<td>56± 1.6</td>
<td>55± 3.0</td>
<td>29± 3.4</td>
<td>22±3.5</td>
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<td>25</td>
<td>4</td>
<td>25.19</td>
<td>33± 9.8</td>
<td>51± 6.4</td>
<td>30± 6.2</td>
<td>52±2.8</td>
<td>45±5.5</td>
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<tr>
<td>J. nigra L.</td>
<td></td>
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</tr>
<tr>
<td>Quercus</td>
<td>50</td>
<td>2</td>
<td>40.96</td>
<td>46±20.0</td>
<td>52±14.0</td>
<td>22±6.0</td>
<td>6± 2.0</td>
<td>5±3.0</td>
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</tr>
<tr>
<td>velutina</td>
<td>Lam.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q. alba L.</td>
<td>50</td>
<td>3</td>
<td>44.45</td>
<td>88.6± 5.9</td>
<td>70±6.1</td>
<td>31.3± 6.4</td>
<td>46± 6.4</td>
<td>6.6± 2.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q. alba L.</td>
<td>50</td>
<td>2</td>
<td>49.40</td>
<td>57± 7.2</td>
<td>16±2.0</td>
<td>43± 5.0</td>
<td>13± 3.0</td>
<td>5±3.0</td>
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<tr>
<td>J. nigra L.</td>
<td>25</td>
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<td>28.35</td>
<td>72± 8.8</td>
<td>46± 6.0</td>
<td>6± 2.0</td>
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<td></td>
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<tr>
<td>nigra L.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>

1Average per cent germination ± one standard error of the mean, the latter being computed from the observations used to compute the averages.

Table 4. Analysis of variance of dormant Quercus velutina Lam. seed.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Degrees of freedom</th>
<th>Mean square</th>
<th>F</th>
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</thead>
<tbody>
<tr>
<td>Per cent germination</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>1</td>
<td>756.9</td>
<td>2.42</td>
</tr>
<tr>
<td>Levels</td>
<td>4</td>
<td>1755.1</td>
<td>7.95**</td>
</tr>
<tr>
<td>Linear</td>
<td></td>
<td>5455.9</td>
<td>24.72**</td>
</tr>
<tr>
<td>Juce</td>
<td>1045.2</td>
<td>4.56*</td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td>3</td>
<td>519.9</td>
<td>2.32</td>
</tr>
<tr>
<td>Error</td>
<td>30</td>
<td>220.7</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Per cent survival</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moisture</td>
<td>1</td>
<td>940.9</td>
<td>4.83*</td>
</tr>
<tr>
<td>Levels</td>
<td>4</td>
<td>1852.1</td>
<td>8.63**</td>
</tr>
<tr>
<td>Linear</td>
<td></td>
<td>5324.7</td>
<td>26.31**</td>
</tr>
<tr>
<td>Juce</td>
<td>534.6</td>
<td>2.74</td>
<td></td>
</tr>
<tr>
<td>Residue</td>
<td>1</td>
<td>631.8</td>
<td>3.24*</td>
</tr>
<tr>
<td>Error</td>
<td>3</td>
<td>660.6</td>
<td>4.93*</td>
</tr>
<tr>
<td>Total</td>
<td>30</td>
<td>194.7</td>
<td></td>
</tr>
</tbody>
</table>

*,**Significant at the .05 and .01 levels, respectively.

Germination of the drier seed declines faster than it does in seed with higher water content.

The average per cent germination of two test plantings of 50 physiologically active Quercus velutina Lam. seed containing 40.96 per cent water did not vary significantly from that of four plantings of 25 soaked dormant Juglans nigra L. seed containing 25.19 per cent water (Table 5). However, the average per cent germination varied significantly from level to level of radiation. There was a significant decline in germination as the level of radiation increased. The relationship was not adequately described by a linear line. This relationship is being studied further, for it did not occur in other species under study. Radiation did not have the same effect on these two treatments of J. nigra L. seed. The drier seed declined in germination as the level of radiation increased and seed with the higher water content did not (Figure 3).

The average per cent germination of four test plantings of 25 non-soaked dormant Juglans nigra L. seed containing 10.08 per cent water did not differ significantly from that of four plantings of 25 soaked dormant J. nigra L. seed containing 26.19 per cent water (Table 6). However, the average per cent germination varied significantly from level to level of radiation. There was a significant decrease in germination as the level of radiation increased. The relationship was not adequately described by a linear line. This relationship is being studied further, for it did not occur in other species under study. Radiation did not have the same effect on these two treatments of J. nigra L. seed. The drier seed declined in germination as the level of radiation increased and seed with the higher water content did not (Figure 3)
slopes of these linear regression lines differed significantly (Table 6). The differences in response to radiation are largely accounted for by differences in slopes of the regression lines.

The average per cent germination of two plantings of 25 physiologically active *Juglans nigra* L. seed containing 28.35 per cent water varied significantly with level of radiation and declined significantly as level of radiation increased. The decline is adequately shown by a straight line (Table 7).

The average per cent germination of three test plantings of 50 non-soaked physiologically active *Quercus alba* L. seed containing 44.45 per cent water varied significantly from that of two plantings of 50 soaked physiologically active *Q. alba* L. seed containing 49.40 per cent water (Table 8). The average per cent germination also varied significantly with the level of radiation. The effect of radiation varied significantly at these two water levels. The slopes of the straight lines fitted to levels in each of the moistures do differ significantly. The significant residue of the interaction of moisture and levels indicates that the seed at these two water contents differs in some aspect other than the linear comparison shown in Figure 5. This is now being reinvestigated to determine whether the same interaction occurs in other seed crops of the same *Quercus alba* L. specimens. A comparison of the effects of radiation dose on seed of two moisture contents was linear for both *Quercus velutina* Lam and *Juglans nigra* L. (Tables 4 and 6).

Seedling survival and growth of the terminal bud are used as a measure of seedling radiosensitiv-
Figure 3. The effects of gamma radiation on germination of Juglans nigra L. seed.

Table 7. Analysis of variance of active Juglans nigra L. seed.

Table 8. Analysis of variance of Quercus alba L. seed.

Table 9. Effect of seedling irradiation.
Seed radiosensitivity does not increase with an increase in water content unless the seed is physiologically active at the time of irradiation. Water could thus affect seed radiosensitivity indirectly by increasing the rate of physiological activity.

The effect of seed irradiation on germination and seedling survival does not differ in general pattern (Compare Figures 1 and 2; 3 and 4, 5 and 6).

Physiological activity does influence seed radiosensitivity, but dormant seedlings irradiated in the fall were as sensitive as the seedlings irradiated in the spring when the leaves were emerging from the buds. Survival of Quercus alba Lam., Quercus velutina Lam., and Liquidambar styraciflua L. irradiated seedlings did not vary significantly from species to species at the levels tested. On the basis of these tests seed radiosensitivity would not be a guide to seedling radiosensitivity.

SUMMARY

Increasing the water content increases the radiosensitivity of Quercus alba L. seed which is physiologically active from the time it ripens. Water content, physiological activity, and radiosensitivity of Quercus velutina Lam., and Juglans nigra L. seed increases as embryo dormancy is broken during stratification. In contrast, the radiosensitivity of dormant Quercus velutina Lam., and Juglans nigra L. seed has an inverse relationship to the seed water content. Water seems to increase seed radiosensitivity indirectly by affecting the rate of physiological activity in these species.

The radiosensitivity of year-old seedlings of Quercus alba L., Q. velutina Lam., and Liquidambar styraciflua L. did not vary significantly from species to species. Physiologically active seedlings of each of these species were not signifi-

Figure 4. The effects of Juglans nigra L. seed irradiation on seedling survival.
- 10.0% per cent water, Y = 53.84-1.00X
\(r^2 = 0.6001\).
- 20.19% per cent water, Y = 37.67+0.35X
\(r^2 = 0.6956\).
- 28.35% per cent water, Y = 70.66-2.40X
\(r^2 = 0.8044\).

Figure 5. The effects of gamma radiation on germination of Quercus alba L. seed.
- 44.45% per cent water, Y = 96.71-8.09X
\(r^2 = 0.8778\).
- 49.40% per cent water, Y = 56.20-5.36X
\(r^2 = 0.8481\).

Figure 6. The effects of Quercus alba L. seed irradiation on seedling survival.
- 44.45% per cent water, Y = 87.96-7.89X
\(r^2 = 0.8746\).
- 49.40% per cent water, Y = 49.75-4.59X
\(r^2 = 0.6234\).
cantly more radiosensitive than dormant seedlings of the same species.

At the levels tested, seed radiosensitivity of these species could not be used as an indicator of seedling sensitivity.

ACKNOWLEDGMENTS

This study was supported by contract number AT(40-1)2066 between the U. S. Atomic Energy Commission and Morehead State College.

Dr. C.R. Weaver, Station Statistician, Ohio Agricultural Experiment Station, Wooster, assisted with the statistical analysis.

REFERENCES


RECOVERY OF VEGETATION ON
ATOMIC TARGET AREAS AT
THE NEVADA TEST SITE
LORA MANGUM SHIELDS and PHILIP V. WELLS
New Mexico Highlands University, Las Vegas, New Mexico

INTRODUCTION
Frenchman and Yucca Flats of the Nevada Test Site have been the scene of more nuclear explosions than any other continental site on earth except possibly in Russia. Field work to interpret the effects of nuclear detonations on natural plant communities in this area was initiated in July, 1957. Since this date coincides with the peak of the last full-scale nuclear operation in Nevada preceding the 1958 moratorium, the full potential impact of individual shots on vegetation may not have been observed. Conclusions are necessarily drawn primarily from two initial target areas and from the predominantly cumulative effects at other shot sites which have functioned as ground zeros during two to four test seasons scheduled in alternate years.

METHODS
At each of five tower target areas, plant cover was measured annually in May and in July, 1958 through 1961, by a modification of the Braun-Blanquet cover class method. At 0.1-mile intervals to a distance of 1.0 mile, cover was estimated within 50 two-by-five decimeter frames spaced along a permanent 100-foot line. Vegetative cover was measured at the same dates on relatively undisturbed control areas and on five blasted sites. Evidence of selective damage and selective recovery in shrubs was documented for the tower ground zeros, for several alpha 1 target areas, and for the venting site of a partially contained underground shot on the east slope of Rainier mesa. Fresh surface soils from within one mile of ground zeros were examined for terrestrial algae and cultured to isolate algae and soil fungi. Plants of three vascular species were irradiated experimentally in the natural environment, using a mobile cobalt-60 source.

OBSERVATIONS
Damage to Vegetation at Target Areas
A nuclear detonation may affect vegetation through thermal, blast, or radiation damage. Injury from thermal or ionizing radiation at above-ground detonation sites is ordinarily masked by blast effects, which vary with stem rigidity and stability of the substratum. A typical airburst, having a yield of approximately 40 kilotons and detonated 300 to 500 feet above the surface, accomplishes total denudation within 0.5 mile. Beyond this point, the area over which shrubs are devastated tends to be asymmetric. On a compact, unsorted alluvial substratum, topped by desert pavement, vegetation survives, with considerable unilateral blast damage, within 0.7 mile of ground zero. On a loose, sandy substratum, however, most shrubs are injured or killed for a distance of 1.0 to 1.6 mile, possibly from disruption of the root systems under the influence of the shock wave. A parallel exists in the greater destruction from earthquake shock on the more unconsolidated substrata, owing to the greater amount of oscillation and displacement (Shields and Wells, 1962). Because of the marked difference in destructive effects to vegetation on two dissimilar types of substratum, prompt radiation can hardly be ascribed a major role in gross damage by nuclear explosions to vegetation beyond the perimeter of complete donudation. Shrub destruction was selective, with some species surviving intact where others were severely damaged or killed. Grayia spinosa Moq., one of the dominant shrubs covering...

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1 Devices deliberately imploded so as not to undergo nuclear fission, but which spew alpha-emitting plutonium about the target area.
much of Yucca Flat, and Yucca brevifolia Engelm. (Figures 1 and 2) were especially susceptible to blast and injury, apparently because of the brittle nature of the wood in these two species.

Certain ground zeros had served as detonation sites in successive test seasons. From the time of the first shot at each target area until the suspension of testing, vegetational recovery had not been allowed to proceed beyond the second year. Preceding the 1957 test series, the second-year recovery vegetation within the 0.5-mile perimeter of complete denuding at two tower ground zeros, selected as representative, had consisted in late July of a 35 to 50 per cent cover of Salsola kali L. A late summer detonation at each site resulted in complete denuding within 0.5 mile and extensive soil removal within 0.1 to 0.3 mile. The burned crowns of bunchgrasses, Corynephorus racemosus (R. et S.) E. Bicker, and Stipa spiciformis Trin. and Rupr., remained alive between 0.3 and 0.9 mile. Some shrubs, such as Larrea divaricata Cav. and Menadorga spinosella Gray, persisted beyond 0.6 to 0.8 mile except on the sandy substratum south of Ground Zero 1.

The shrubs surviving nearest to ground zeros undoubtedly sustained exposures of intense radiation. The estimated cumulative air dose at 0.6 mile from ground zero in Area 1 is on the order of 14,000 roentgens (Lackey, J. G., personal communication). Nevertheless, most shrubs surviving more or less severe mechanical injury at this distance flowered and fruited in 1961, and some of those species produced an abundance of seeds with well-developed embryos. The flowering shrub survivors included: Coleogyne ramosissima Torr., Gravia spinosa, Larrea divaricata, Lycium andersonii Gray, and Menadorga spinosella. Thermal and ionizing radiation, however, may have exercised a selective action on seeds in the soil between 0.1 to 0.3 and 0.6 mile from ground zeros. At sites of surface alpha shots of soil, most years previous, vegetation shows no apparent gross thermal, blast, or radiation damage. Annual species grow through breaks in the asphalt pads where surface readings from the heavy pads were greater than 0.100 alpha counts per minute.

In the vicinity of a crater formed by a partially contained underground shot entombed on the east face of Blaisier mesa (Blaisier, October, 1958), evidence of damage to vegetation, and to coniferous trees in particular, spread progressively for two years, both within an initially heated zone 1,500 feet in diameter and over an expanding radius beyond. Three deep-rooted species incapable of crown sprouting (Pinus monophylla Torr. and Frem., Juniperus osteosperma (Torr.) Little, and Artemisia tridentata Nutt.) were killed at 0.3 mile west of the mesa rim above the shot site. Shallow-rooted and crown-sprouting species survived or recovered except in areas of excessive surface disturbance, which suggests root damage rather than radiation or thermal injury as the probable cause of killing.

Soil algae and fungi appear to have been destroyed or removed with the soil within 0.6 mile of tower ground zeros. Since certain species of both categories have been demonstrated to survive more than 640,000 roentgens of gamma radiation exposure at the Brookhaven National Laboratory (Shields, Durrell, and Sparrow, 1961), thermal damage appears to explain their absence from the denuded area. More recently, spore-algal spores in Nevada Test Site soils have been found to develop normal appearing cultures following acute exposures up to 5,000,000 roentgens from a cobalt-60 source (Shields, Durrell and Sparrow, unpublished data).

Recovery of Vegetation at Target Areas

The pattern of initial vegetational recovery was similar on all areas bared by tower shots. Seeds within 0.1 to 0.3 mile of different ground zeros may have been removed with the soil. Within this zone where heat, blast, and radiation levels were highest, plant cover in the spring following denuding had consisted of a sparse representation of annuals. Between the 0.1 to 0.3-mile perimeter of pronounced soil removal and 0.6 mile, spring annuals in the first year of recovery (Figure 3) appeared to develop primarily from surviving seeds.

![Figure 3: Spring-maturing annuals 0.3 mile from ground zero in the first year of recovery, May, 1958, approximately ten months following detonation.](image)

The bulk of the vegetative cover within 0.6 mile was contributed by two species, Mentzelia albicaulis Bougl. at five tower ground zeros and Erodium circumcinctum (L.) L’Her at two. For four tower target areas, Mentzelia contributed more than any other annual species within 1.0 mile. The peak cover by this species, occurring at 0.2 to 0.6 mile from individual detonation sites, ranged from 35 to 62 per cent. Beyond 0.6 mile, the per cent cover by other species and the total number of species generally increased. Gilia latiloba A. Gray, Erodium circumcinctum, and Chaenactis stevioloids Hook and Arn. were the species second, third, and fourth high, respectively. On the surrounding control plots Chaenactis stevioloids was the dominant annual, followed by Mentzelia albicaulis with a 3 to 11 per cent coverage. Ground cover by spring annuals between 0.4 and 0.8 mile from ground zeros exceeded total cover on control plots, reaching a peak of 70 to 171 per cent between 0.4 and 0.8 mile at four of five tower target areas. When the spring annuals completed their reproductive cycles and died in late May, Salsola kali was developing into a widely spaced stand in the area of greatest soil loosening and removal within 0.1 to 0.3 mile of ground zeros. By September these plants had matured to a size of one to two meters in diameter (Figure 4.)

The high coverage by spring annuals in 1958 was associated with favorable precipitation. A decrease in the second, third, and fourth-year cover at target areas was largely the result of limited precipitation. Linear dimensions of all annual species were greatly reduced in 1959, many flowering in a depauperate, scarcely branched stage.
Though the 1960 and 1961 growing seasons were also dry, per cent cover was higher; but, as in the control vegetation, it was nearer the 1958 than the 1956 values. During the second year of recovery (1960), the Mentzelia albicaulis stand narrowed centripetally by approximately half, and Salsola kali within 0.5 mile of ground zeros formed a dense stand of smaller plants, scarcely branched and lacking the tumbling habit. Mentzelia tended to be replaced by Erodium at one ground zero and by Chaenactis stevoviades elsewhere. Mentzelia, in 1960 again the dominant between 0.3 and 0.6 mile from ground zeros, was subordinated to Chaenactis stevoviades and Bromus rubens L. in 1961. By 1961 Salsola kali was represented by only scattered individual plants at all ground zeros.

During the four-year period since the last nuclear test, Chaenactis stevoviades and Bromus rubens have invaded progressively in the direction of ground zeros. In fact, compared to these two species, cover by other annuals was insignificant at Ground Zero 4 in the fourth year of recovery. Alternating with extensive patches of Chaenactis, localized stands of Bromus rubens in few places in Area 4 resembled the grassland scours of natural burns in the Coleogyne-Gravina zone of Midvalley, now covered by Bromus rubens with scattered Stipa speciosa. Midvalley, to the west of Yucca Flat, has never served as an atomic test site.

After seven years of nuclear testing followed by four years during which the ground zeros have been little disturbed, the composition of the vegetation has changed marginal to the denuded areas. Certain woody species are capable of sprouting from the stem base when the tops are destroyed. The crown-sprouting habit is common to all the shrubs surviving and now recovering within 0.6 to 0.8 mile of ground zeros: Atriplex canescens (Parsh.) Nutt., Hymenoclea salicina T. and G., Larrea divaricata, and Hymenoclea spinosa (Shields and Wells, 1962). The non-crown-sprouting dominants, Gravida spinosa and Coleogyne ramosissima, are eliminated to a greater distance. The bunchgrasses Stipa speciosa, at Ground Zero 4, and Cryptopis hymenoides, at Ground Zero 1, show a marked increase in the zone of damage to shrubs. The weedy perennial Mirabilis pudica Barneby and Atriplex canescens, a saltbush characteristic of disturbed areas, are increasing. Other pioneer, weedy shrubs or subshrubs, such as.negatively, and Sphaeralcea ambigua Gray, are found in unusual numbers in the zone of injury to the original shrub cover, primarily on the more compact type of substratum with desert pavement. These species appear to be encroaching about the margins of the totally denuded areas at certain ground zero sites. These short-term changes in perennial vegetation are analogous to succession as confirmed by observations of older disturbances in the same general area (Wells, 1961).

Soil fungi, apparently introduced, were growing within a short time on all ground zeros (Durrell and Shields, 1961). One species of terrestrial algae, Microcoleus vaginatus (Vauch.) Gem., became re-established by ten months following detonation within 0.4 mile of the ground zero where moisture relations were most favorable. Otherwise, algae have not been found in natural soil growths nearer than 0.6 mile from ground zeros.

Experimental Irradiation of Species in the Field

A 10,000 roentgen total exposure from a mobile 14.4-curie cobalt-60 source had no apparent effect on Larrea divaricata nor Stanleya pinnata (Pursh) Brit. In Pinus monophylla Torr. and Frem., however, the same exposure killed parts within 13 inches from the source (doses above 1,300 roentgens) within four months and produced a decreasing gradient of growth inhibition effects out to a distance of five feet (Brandenburg et al., 1962). At doses between 50 and 100 roentgens, at two to four feet, terminal bud inhibition or death subsequent to elongation was accompanied by the development of lateral (dormant) buds, which figure significantly in recovery from radiation damage. Approximately one-fourth of the needles forming on spicles collected four to six feet from the source showed one of two vascular anomalies: (a) a reduction of vascular tissue, frequently to the point of disappearance, or (b) a double vascular strand (Brandenburg et al., 1962).

SUMMARY

The typical nuclear detonation at the Nevada Test Site, an airburst of a 20- to 40-kiloton, 8.5-mile yield, denuded a zone of desert shrub vegetation about 0.8 mile in radius. Symmetric blast damage to shrubs extended to a greater distance, in some cases to beyond one mile, varying with species and stability of the substratum. Gross injury to vegetation appears to be largely from blast and thermal effects. The spring following detonation, ground cover by annuals between 0.4 and 0.8 mile from different ground zeros exceeded total cover in the control vegetation. Beyond the perimeter of denudation, recovery is evident in the crown sprouting of several shrub species, in the appearance of weedy perennials, and in the prominence of bunchgrasses. During a four-year study period (1960 through 1964) it has not been possible to establish an unequivocal relation between killing, injury, or morphological aberration in vegetation and ionizing radiation from nuclear detonations.

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The irradiation experiment was initiated by Drs. Howard L. Mills and William H. Rickard, then of the project staff.

REFERENCES


INTRODUCTION

In recent years one of the major problems in radiation ecology has been the accurate determina-
tion of dosages of ionizing radiation. This prob-
lem has become particularly acute in the radia-
tion ecology program of Emory University because measure-
ments are required of a mixed field of neutron and gamma radiation attenuated by terrain and vegeta-
tion and by shielding at the source. The radia-
tion source is a nuclear reactor designed for
shielding studies operated by the Lockheed Air-
craft Corporation near Dawsonville, Georgia. The
remote, heavily wooded environment of varied ter-
rain is irradiated by the large leakage flux of the
reactor, and it is the area within a radius of
3600 feet which has been under ecological study
since the reactor began operation in December,
1958.

The purpose of this project is accurately to
map the radiation dosages for varying reactor op-
erations and to determine the general effects of ter-
rain and vegetation on these dosages. The neutron
dose was evaluated with neutron activation detec-
tors and the gamma-ray dose with chemical Dosim-
eters, film badges, and activated phosphate glass dosimeters. These detectors were chosen because of their size,
low cost, availability, and reliability of results.

The reactor and the radiation field are

THE DOSE DETECTION SYSTEM

Neutron activation detectors were used for the
field measurements because of their sensitivity to
neutrons of specific energy ranges and small size.

The basic theory of the activation detector is that
neutron reactions with certain nuclides result in
radioactive product nuclides. The measurement of
the product radioactivity can be used to calculate
the neutron fluence and the energy spectrum
(Price, 1958, pp. 281-294). Neutrons are emitted
from the reactor at energies ranging from thermal
(0.025 electron volts) to fast (ten million elec-
tron volts) (Wilson et al., 1960). The thermal
and resonance neutron distributions were measured
by neutron reactions with cobalt, sodium, manganese,
and gold detectors, and the fast distribution was
measured using sulfur, thorium, and nickel thresh-
old detectors. By using a series of these detectors
at each field location a neutron energy spectrum
could be constructed. Absorbed doses could be ob-
tained using the model of Snyder and Neufeld (Gold-
342-350). A more detailed description of the neu-
tron dose determination is given by Cowan (1961).

The activation detector materials were pre-
pared in pellet, powder, or foil configurations
and placed in small polyethylene vials which were
installed at the detection stations in the field.

The neutron flux distribution measurements were
augmented by small detectors inside paraffin and Lucite moderators which slowed down a
portion of the resonance and fast neutrons to ther-
nal energies, thus causing the activation in the
termal detectors to be increased. The main value
of these moderators was in providing an experiment-
al check on the thermal flux distribution at large
distances from the reactor where the incident neu-
tron density was lowest.

The primary gamma-ray measurements were made
with the ordinary personnel radiation monitoring
film badges and with chemical dosimeters. These
measurements were augmented with a selected number of silver-activated phosphate glass dosimeters, but these were used primarily to test their adaptability
as field detectors. The film badges were pri-
marily used for measuring low doses, while the other
two dosimeters were useful for high doses (Cowan,
1961). The film badges were protected against ad-
verse weather conditions by enclosing them with
thin plastic and placing each beneath a light-ref-
lecting metal surface. The chemical dosimeters
were enclosed in lithium glass tubes to filter the
thermal neutrons to which the detectors are sensi-
tive. The accuracy of the chemical dosimeters for
the dose rates and ranges encountered is within
± 10 per cent, while the accuracy of the film and
glass dosimeters is within ± 20 per cent. All
dose measurements were expressed in rads, one rad
being equal to 100 ergs per gram.

THE REACTOR AND THE RADIATION AREA

The reactor is considered unshiled in the
sense that a large neutron and gamma-ray flux is
released into the environment. The reactor is sur-
rrounded, however, with a borated shield plate and
aluminum shield tanks which can be filled with varying
amounts of water to attenuate portions of the
leakage flux (Lockheed Aircraft Corporation, 1958).

The variable shielding has a decided effect on the nature and quantity of radia-
tion leaving the source and its effect is to di-
vide the radiation field into four quadrants, desig-
nated the northwest, northeast, southeast, and south-
west, each quadrant receiving an intensity of radia-
tion governed by the tankshielding in that particu-
lar quadrant. The tank configuration also necessi-
tates expressing the measured dose in terms of
rads per megawatt-hour for the tanks-empty or the
 tanks-full configurations, respectively. The reac-
tor and the radiation field are shown in Figure 1.

Detection stations were subjectively placed at
68 locations, each station consisting of a series of
neutron and gamma-ray detectors. Twenty-three of
these stations were situated in the reactor "line-
of-sight." This designation means that from each
station so selected the reactor can be seen with
relatively few obstructions from trees, foliage,
ground, and terrain, and the measured dose constitutes an "ideal" dose unperturbed by local features.

Measurements from a series of these stations allow a
determination of the dose curve to be constructed from
which the ideal dose can be known at any distance
from the reactor.

The remaining stations were placed at specific
locations to measure the dose under shielding con-
ditions. The variation of dose with elevation in
trees was measured at five locations with detectors
placed at elevations above the ground from 1 to 25
feet. Vertical dose gradients from four feet above
the ground to one foot depths in the soil were mea-
sured at two locations. Four pairs of stations,
one shielded and the other line-of-sight, were
used to determine transverse shielding due to either
terrain or vegetation or both. The transverse neu-
tron dose gradient through trees was determined at
six locations by neutron detectors placed on the
front, inside, and behind selected trees. A line
of seven stations was placed in a completely
shielded area in the southwest quadrant from 400 to
311
Figure 1. The reactor and the radiation area. The reactor is housed within the aluminum building. The railroad lies in the center of the northeast quadrant.

Figure 2. A typical radiation detection station. Neutron activation detectors consisting of cobalt, manganese, sodium carbonate, gold, thorium, nickel, and sulfur were placed in polyethylene vials in pellet, powder, or foil configurations. The Lucite moderators were used to implement the thermal neutron flux measurements. A chemical gamma-ray dosimeter is shown mounted at the center and a gamma-ray film badge is attached beneath the tin can shown at the right.

700 feet from the reactor. The other stations were placed singly behind hills, in ravines, and in heavily wooded areas.

Most of the vegetation shielding in the area resulted from pine (Pinus taeda), oak (Quercus spp.), and hickory (Carya spp.) growths on the hills and from river birch (Betula nigra) thickets near the river. Terrain shielding varied from small dirt mounds to ravines and gulleys and large hills.

An example of a detector station including the various neutron and gamma-ray detectors is shown in Figure 2. The station numbers and locations are shown on the topographical map in Figure 3.

RESULTS AND DISCUSSION

The primary radiation measurements were made during a 2,208 megawatt-hour operation in August, 1960 (Figure 4), during which the shield tanks were empty in the northwest quadrant, full in the southeast and southwest quadrants, and full in the northeast quadrant except for a 149 megawatt-hour operation with shield tanks empty. The boral plate on the northwest side of the reactor was removed for this operation. Previous experiments have shown that the boral plate, which was designed to absorb thermal neutrons, has little effect on the field dosages, since it is the fast and resonance neutrons which contribute primarily to the neutron dose (Cowan, 1961). The gamma activations from the neutron detectors were counted with a three-inch sodium iodide crystal scintillation, well-type counter in conjunction with a single-channel pulse height analyzer and with a gas-flow counter. The activated glass was measured on a spectrophotofluorometer and the other gamma-ray dosimeters were evaluated by the suppliers.

Due to low counting statistics obtained with the thorium and nickel threshold detectors, only the data obtained from the sulfur specimens were used to evaluate the fast neutron flux. This necessitated assuming a fission spectrum in the region from one to ten million electron volts, but this was believed justified since spectral measurements made near the reactor face have indicated that a fission spectrum is followed to a good approximation in large air volumes (Wilson et al., 1960). A further justification is the fact that
Figure 3. Location of detection Stations 1 through 68. The vertical scale is exaggerated by approximately a factor of two over the horizontal scale. The reactor building is shown at the far left. The higher numbered stations in the tree profiles correspond to higher elevations.

Figure 4. Reactor operation for the first two years. Note the two high level periods, the first in June of 1959, the second in August of 1960. These two accounted for approximately 80 per cent of the radiation dosages for the entire period. In the northwest quadrant, 16 per cent was received in June and 64 per cent in August. In the northeast and southeast quadrants, 32 per cent was received in June and 42 per cent in August, and in the southwest quadrant, 16 per cent was received in June and 64 per cent in August.

The resonance spectra in the region from 0.4 electron volts to almost one million electron volts were found to have the same shape and general characteristics at the field stations as the resonance spectra measured near the reactor face (Cowen, 1961; Wilson et al., 1960). It was found that the resonance and fission portions of the spectra connected smoothly for nearly all of the stations.

The combined line-of-sight neutron and gamma-ray dose rates were determined for the tanks-empty and the tanks-full configurations by adding the neutron and gamma-ray dose rates for the line-of-sight stations along the northwest and southeast beam lines. The variations at the line-of-sight dose rate with distance and tank configuration is illustrated in Figure 5. It was found that the gamma-ray dose rate is higher than the neutron dose rate becomes greater with distance. The combined dose rate when the shield tanks are full is approximately one-fourth that for the tanks empty, and the gamma-ray dose rate is quite predominant in this case. The effect of filling the tanks decreases the neutron dose rate by a factor of 15 to 30, this factor decreasing with distance. At the same time the gamma-ray dose rate is decreased only by a factor of four.

The accumulated combined dose over any given period of time is determined by multiplying the combined dose rates for tanks-full and tanks-empty by the reactor operation time in megawatt-hours for each configuration and adding the two components. The reactor operations of primary interest to ecological studies of the area occurred in June, 1959, and August, 1960 (Figure 4). Until August, 1960, the shield tanks were empty an almost equal amount of time in the northwest, northeast, and southeast quadrants, and the ratio of empty to full operation was 11 to 1 through June, 1959, 6 to 1 through December, 1959, and 3.4 to 1 through June, 1960. After August the ratio changed to 11 to 1 in the northwest quadrant, 0.47 to 1 in the northeast quadrant, and 0.38 to 1 in the southwest quadrant. The two-year accumulated dose was computed for the period from December, 1958, through December, 1960, and the data were used to construct the isodose map of Figure 6. The accumulated dose is highest in the northwest quadrant and decreases in the northeast, southeast, and southwest quadrants, respectively, illustrating the effect of the long reactor operation with tanks empty during August, 1960. The neutron dose varies more from quadrant to quadrant than does the gamma-ray dose because of the greater variation of neutrons in the filled shield tanks.
the gamma-ray dosages can be used to compute the attenuation factors without introducing an appreciable error, since neutrons contribute only a small percentage to the total dose rate. The empty configuration, however, was of the greatest biological importance because of the higher dose rates and because the reactor operated predominantly with tanks empty over the two-year period. The attenuation factors were evaluated, therefore, only for the tanks-empty configuration.

Probably the most significant shielding effects were observed from the measurements at Stations 46 through 53 located along the east-southeast beam line in a mature oak-hickory forest stand (Figure 7). Only Station 46 at 415 feet is in the line of sight. The upper circles show the expected line-of-sight dose while the bottom circles show the actual dose resulting from terrain and vegetation shielding. Of exceptional interest is the relatively little change in the shielded dose from 400 to 800 feet compared with the change in the line-of-sight dose for the same distances. This is because the neutron percentage of the shielded dose increases with distance, as opposed to line-of-sight behavior, and is probably due to forward scattering of the neutrons. The gamma-ray dose is more sharply attenuated by terrain than is the neutron dose. At the pair profile consisting of Stations 48 and 49 at 500 feet, however, it is the neutron dose which is more sharply attenuated in passing through the tree at that location. Figure 8 shows this profile.

The attenuation effects of terrain and vegetation were determined by comparing the measured dose rate with the line-of-sight dose rate for the same quadrant and at the same distance as the shielded station. The percentage obtained by dividing the measured dose rate by the line-of-sight dose rate is referred to as the attenuation factor. Since the gamma-to-neutron dose ratios vary with shield tank configuration, the attenuation factors will also vary. For the tanks-full configuration,
fact that Station 51 at 595 feet, which is located in a wooded ravine about 20 feet below the adjacent stations, still received approximately the same dose as Station 50 at 590 feet which is in a less shielded area. Figure 9 shows the detector arrangement for the profile consisting of Stations 46 and 47 at 415 feet. The dose at the shielded station was 21 per cent of the dose measured by the line-of-sight station, and the gamma-to-neutron ratio was shifted from 2.3 to 1 to 2.3. These data are supported by visual observations of plant damage. Typical bud growth in this area is illustrated in Figure 10, the arrow indicating the direction of incident radiation. Note that there is no bud growth on the side of the trees facing the reactor.

Figure 9. Detection Stations 46 and 47, 415 feet from the reactor on the east-southeast beam line. The dose at the ground level (Station 47) is 21 per cent of the dose in the line-of-sight at Station 46. This is a case of pure terrain shielding with a predominant decrease in gamma dose.

Figure 10. Vegetation in the area of the east-southeast beam line. The line-of-sight of incident radiation is indicated by the arrow. Note the small amount of vegetation above the line-of-sight and the absence of bud growth on the side of the trees facing the reactor.

and the detector arrangement. The hole in the middle was made to accommodate a thermal neutron detector. The extent of scatter is further emphasized by the

Figure 11. Dose detection profile at Stations 36, 37, and 38, 1,370 feet from the reactor on the northeast beam line. The lower two stations are partially shielded by a small hill to the left. The dosages at the middle (Station 37) and bottom (Station 36) stations are 31 and 80 per cent, respectively, of the line-of-sight dose measured at the top station.

Another important terrain effect is the variation of dose with elevation above the ground. At the profile shown in Figure 11, Station 38 at the top is in the line of sight and the lower two stations are shielded by a small hill. The attenuation factors for Station 36 at the bottom and Station 37 at the middle were 31 and 80 per cent, respectively. The gamma-ray dose was predominantly decreased more than the neutron dose for the former station, and for the latter, the neutron and gamma-ray doses were equally decreased. The other shielded profiles showed similar dose variations, and the general results clearly illustrate the reduction in dose with a decrease in elevation in shielded areas. At the areas which are not
shielded, however, the dose variations with elevation appear to be small. At the profile consisting of stations 6 through 80, for example, nearly all stations were in the line of sight, and very slight changes in the dose were measured from 1 to 15 feet above the ground.

The results of the dose penetration measurements in the soil compare favorably at the two underground stations. The attenuation factor for Station 2 at 500 feet is 12.0 per cent and the gamma-to-neutron dose ratio is 1.40. The attenuation factor for Station 5 at 650 feet is 12.8 per cent, and the gamma-to-neutron dose ratio is 1.35. There was a predominant decrease in the gamma-ray dose at these stations.

At the pair profile at 825 feet in the northwest quadrant. Station 9 was in the line of sight and Station 10 was attached to the front side of a three-foot diameter beechnut tree. In this case the neutrons were attenuated more than the gamma rays; the gamma-to-neutron dose ratio was 3.97 and the line-of-sight dose ratio was 3.22. This illustrates a case of pure vegetation shielding.

It was generally found that in those locations where vegetation shielded only, the neutron dose was decreased much more than the gamma-ray dose, and in those which were terrain shielded only, the gamma-ray dose was decreased much more than the neutron dose. A comparison could be made between the measured gamma-to-neutron dose ratio and the line-of-sight gamma-to-neutron dose ratio. If the former ratio was less than the line-of-sight ratio, then terrain shielding was predominant, and if it were greater, vegetation shielding was predominant. A large difference in the ratio indicates a great degree of predominance for one type of shielding over the other, and equal or near equal ratios indicate that neither type of shielding is predominant. The attenuation factors and the shieldings are summarized for the shielded stations in Table 1. The dose rates are in roads per megawatt-hour. Table 2 summarizes the attenuation data for the profiles which were not in the line of sight. It was assumed here that the station having the maximum dose at each profile was in the direct beam, or in other words, that no dose attenuation occurred prior to reaching this station. The data in this table indicate the local rather than the over-all dose attenuation. Although Stations 63 through 67 were in a quadrant for which the shield tanks were always filled, the dose rates for the tanks-empty configuration was used for purposes of comparison. Note that the attenuation factors are always lower for terrain than for vegetation. Especially interesting is the attenuation for equivalent thicknesses of the two media. At Station 49, for example, 77 per cent of the dose is transmitted through the one-foot diameter oak at that location, while at Station 2 only 12 per cent of the dose is transmitted through the one-foot thickness of soil. Scattering may have contributed some to the former dose, but the contribution is not believed large enough to have caused the significant difference. The stations for which a definite line-of-sight dose curve could not be established or for which the statistical accuracy of the measurements was inadequate are omitted from these tables.

A difference of approximately 40 per cent was found between the tanks-empty line-of-sight gamma-ray dose values measured with the chemical dosimeters and those measured with film dosimeters, with the chemical dosimeters showing the higher values. This could be partially accounted for by the efficiency of each detector, but is probably due to slight differences in calibrations in the two systems. The chemical dosimeter data were used for the line-of-sight dose rates because each detector was exposed for the same length of time and smoother line-of-sight dose curves could be constructed. The chemical dosimeter data are also consistent with extrapolated gamma-ray

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### Table 1. Attenuation factors at shielded stations with shield tanks empty.

<table>
<thead>
<tr>
<th>Station number</th>
<th>Attenuation factor</th>
<th>LOS dose rate</th>
<th>Measured dose rate</th>
<th>Per cent error measured dose rate</th>
<th>Measured gamma-to-neutron ratio</th>
<th>LOS gamma-to-neutron ratio</th>
<th>Predominant shielding</th>
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1 Minimum value in parenthesis.
2 LOS = line of sight.
Table 2. Dose attenuation at station profiles with shield tanks empty.

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1 LOS = line of sight.

Assuming the calibration of these detectors to be correct, an error of ± 10 per cent is assigned to the line-of-sight gamma-ray dose measurements. In shielded areas the dose attenuation factors are fairly consistent for both the chemical and film dosimeters. When the dose rates for each dosimeter are compared with their respective line-of-sight dose rates, the agreement is 90 per cent. The chemical and film dosimeters were used in shielded areas and a ± 20 per cent accuracy is assigned to these values.

Errors in the neutron dose measurements depend primarily on the accuracy of the activation cross sections, the accuracy of the Snyder–Neufeld dose conversion table, and the statistical counting accuracy. The thermal and resonance activation cross sections are known within ± 10 per cent and the sulfur threshold cross section, within about ± 20 per cent. The probable error involved in using the Snyder–Neufeld model is about ± 10 per cent (Snyder and Neufeld, 1955). The counting statistics were accurate to within ± 3 per cent for the thermal and resonance activation detectors. The counting statistics of the sulfur specimens were not as good, but an error of less than ± 3 per cent was introduced in the neutron dose rates at the line-of-sight stations and at the shielded stations within ± 10 per cent. The error in the neutron dose rate is within ± 10 per cent for the other shielded stations shown in the tables except for Stations 14 (± 26 per cent), 44 (± 21 per cent), 45 (± 16 per cent), 46 (± 14 per cent), and 64 (± 12 per cent). Probably the most significant error in the neutron measurements was introduced by the assumption of a fission spectrum in the fast energy region. Previous experiments have shown that fission spectrum can be measured to within accuracies of ± 30 to ± 40 per cent using threshold detectors (Wilson et al., 1960). In consideration of the fact that the resonance and fission portions of the spectra connected smoothly, a maximum of 99.9 per cent is therefore assigned to the values of the neutron doses in the fast region.

From the above estimates of errors, the accuracies of the combined neutron and gamma dose rates could be computed. The line-of-sight dose rates with shield tanks empty are accurate to within ± 22 per cent, and with shield tanks full, within ± 12 per cent. The dose rate accuracies for the shielded stations are shown in Tables 1 and 2.

The uncertainties in computing the attenuation factors are not as large as the above values. This is because the neutron attenuation is computed on the basis of relative dose rates and is therefore dependent primarily on the statistical counting accuracy. The computed errors in the attenuation factors are shown in Tables 1 and 2.

As an example of the method used to evaluate errors, consider Station 2. At this station, 41.6 per cent of the dose rate is due to neutrons and 58.4 per cent to gamma rays. Fast neutrons comprise 34.6 per cent and resonance neutrons 45.4 per cent of the neutron dose rate. The error due to uncertainties in known cross-sections and the assignment of a fission spectrum in the fast region was taken as 40 per cent (believed conservative). The cross-section uncertainty for resonance neutrons is 10 per cent. The counting errors for fast and resonance neutrons are 3.3 and 0.5 per cent, respectively. Adding these errors for each component and multiplying by the per cent of each component, we get a fast neutron error of 32.7 per cent and a resonance error of 9.3 per cent. The sum of these is 32.0 per cent. The neutron dose rate error for the neutron plus gamma dose rate or total dose rate is then 41.6 per cent of 32.0 per cent or 13.3 per cent. The gamma-ray dosimeters used at this station were assigned an accuracy of 20 per cent. The error in the neutron plus gamma dose is then 58.4 per cent of 20 per cent, or 11.7 per cent. The total error is 11.7 + 13.3, or 25 per cent. In computing the attenuation factor errors, the gamma dosimeter error and only the counting errors for neutrons were considered, since attenuation factors are based on relative dose rates only. The neutron error of the total dose rate is 41.6 per cent of 1.3 ± 0.5 per cent, or 0.8 per cent. Adding this to the gamma error of 11.7 per cent, the error is 12.5 per cent. The line-of-sight gamma-ray neutron error at the distance (500 feet) are 63.7 and 36.3 per cent, respectively. Multiplying each of these by the gamma dosimeter error of 10 per cent (the line-of-sight value) and the neutron counting error of 0.7 per cent and adding gives a line-of-sight error of 7 per cent. The measured dose rate of 2.34 was multiplied by 12.5 per cent, and the result was added and subtracted from 2.34 to give 2.63 and 2.06, respectively. The line-of-sight dose rate of 19.5 was multiplied by 7 per cent to give 20.9 and 18.3. The maximum attenuation factor was found by dividing 2.63 by 18.3, giving 0.114 per cent; the minimum factor was found by dividing 2.06 by 20.9, giving 0.113 per cent. Half the difference between 14.4 per cent and 9.9 per cent is 2.3 per cent. As expressed in the table, the range is ± 2.3 per cent. The attenuation factor shown in the tables was found by dividing 2.34 by 19.5, giving 0.12 per cent.

SUMMARY AND CONCLUSIONS

For the empty shield tank configuration the line-of-sight dose rate varied from 14 rads per megawatt-hour at 600 feet to 1.2 rads per megawatt-hour at 1,500 feet from the reactor. The gamma-ray portion of this dose rate was 2 to 3 times the neutron portion. When the reactor shield tanks were full, the dose rates were reduced by approximately a factor of four, and the gamma portion was 20 to 50 times the neutron portion.

It was found in naturally shielded areas that neutrons were proportionally attenuated more than gamma-rays by vegetation. Conversely, the soil attenuated gamma-rays proportionally more than neutrons. The terrain data at all, reduced more total dose attenuation than did the vegetation. This behavior is in accordance with what could have been anticipated on the basis of the scattering and absorption cross sections of soil and plant atoms for gamma rays and neutrons. In particular, it is believed that the large hydrogenous content of plants is responsible for the proportionally large attenuation of neutrons in areas shielded by vegetation.
One of the most significant results of this study was the observation that large dosages result in locations which are partially or completely obscured from the direct beam of the reactor. This can be attributed to initial air scattering and subsequent scattering by terrain and vegetation. Predominant scattering of the radiation in the direction of the incident beam was also observed in shielded areas. Maximum radiation protection in shielded areas was afforded at locations adjacent to the ground level or on the back sides of trees away from the reactor and is attributed to the ground and vegetation at these locations absorbing a large part of the scattered radiation which would otherwise have contributed to the dose.

From the data of this study, it is possible to reconstruct the radiation history at practically any location in the field for any given reactor operation and shield tank configuration.

ACKNOWLEDGMENTS

This work was supported through contract number AT(40-1)2412 between the U. S. Atomic Energy Commission and Emory University and in part by contract number AF 31845 of the U. S. Air Force with Lockheed Aircraft Corporation. Our gratitude is expressed to Dr. Robert H. Rohrer, Professor of Physics, to personnel of the Department of Radiology of Emory University, and to Lockheed Georgia Nuclear Laboratories and to many of their personnel.

REFERENCES


INFLUENCE OF FOUR ROCKY MOUNTAIN REGIONAL ENVIRONMENTS ON PEA PLANTS GROWN FROM IRRADIATED SEEDS

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INTRODUCTION

The effect of ionizing radiation on plant growth has been studied intensively (see Dager, 1958, 1956; Johnson, 1956; Gueneckel and Sparrow, 1954, 1956; Engel, 1957 for comprehensive reviews). Yet, many phases are still controversial. Some of the major controversies are concerned with instances of low or intermediate levels of irradiation, particularly as to growth stimulation. Growth stimulation or increase in vegetative amount has been reported frequently since the earliest days of radiation experimentation, but results are still contradictory, and Gunckel and Sparrow's (1954) statement that "...the problem of differential radiosensitivity is a difficult and complex one which is poorly understood" is still valid.

It has been amply demonstrated that radiosensitive systems of plants may be modified by a large number of factors such as their chemical-physical condition and history, genetic make-up, physical factors associated with the radiation dose accumulated, and environmental situations encountered. However, publications concerning the alteration of radiosensitivity by external post-irradiation environments are scarce. Of the six references listed under this category in the comprehensive bibliography of Sparrow et al. (1958) only three (Smith and Caldecott, 1948; Gray, 1954; Greenberg, 1955) pertain to growth of vascular plants.

During the summer of 1960, an experiment was designed and executed to gain information on the amount that several different post-irradiation environments might alter the effects of acute doses of low and intermediate levels of ionizing radiation. The post-irradiation environments chosen were considered to be representative of four climax ecological plant regions (lower montane, upper montane, sub-alpine, and alpine tundra) on the east slope of the Colorado Front Range, which provides a very wide range of environmental conditions. The experiment was also meant to test the validity of a universally accepted principle in ecology that, whenever an organism is growing in a situation which is near the limit of its tolerance to one or more factors, its sensitivity to other factors is often increased. Although not often stated, this principle has some intrinsic considerations: (1) if an organism is growing in an optimum environment it may withstand a greater intensity of one deleterious factor before it shows an effect, and (2) if an organism is growing in an environment unfavorable for one or more factors, another factor or group of factors may compensate for the limiting factor.

Some evidence exists in recent radiobiological literature that these ecological principles can be applied to several kinds of organisms (Pigge and Wichterman, 1959; Lebedinsky et al., 1958; Kuzin, 1958; Daly, 1960).

METHODS AND MATERIALS

A garden variety (early Alaskan) of peas (Pisum sativum) was selected for the experiment because, according to Went (1957) "they belong to the most uniform experimental plant material available" and previous experimentation had demonstrated that peas could grow in the proposed study gardens. The pea seeds were sorted and intermediate-sized seeds were selected and air-dried in an open container for several days at room temperature (about 700 Fahrenheit). The carefully sorted seeds were considered to represent the most uniform growth stage obtainable to use for the radiosensitivity study. There were irradiated on July 19, 1960, with gamma rays from a 1,000 curie cesium-137 source through the cooperation of Dr. Bert Tolbert of the University of Colorado, Department of Chemistry. The dose rate was approximately 1,000 rads per hour, and the doses of irradiation were 0, 100, 500, 1,000 and 5,000 rads.

The peas were planted in experimental gardens (see Figure 1) which are adjacent to environmental measurement stations at A = 1.5, 5, 2, 25 meters; (B = 1) 5, 000, 2, 50 meters; (C = 1) 10, 000, 3, 44 meters; and (D = 1) 12, 300, 3, 750 meters feet in altitude on the east slope of the Colorado Front Range west of Boulder. These stations are operated by the University of Colorado, Institute of Arctic and Alpine Research. See Marr (1961) for details of station location and instrumentation. Each environmental measurement station was located in an attempt to record representations occurring within one of four climax regions (lower montane, upper montane, sub-alpine, and alpine tundra) of the southern Rocky Mountains.

The portion of each garden selected for plantings appeared to have soil with homogeneous characteristics. The seed bed was prepared by thoroughly mixing the top soil first with a rototiller (mechanical home cultivator) and finally with a hoe and garden rake. The pea seeds were planted in rows in essentially the same manner at all stations, with treatments systematically placed. The seeds were placed about two inches apart in shallow trenches, approximately 1 inch deep, and then were covered with approximately one inch of soil so that a slight mound was over the peas. One exception to this manner of planting was made at Station A-1 in the row of peas irradiated at 5,000 rads as a result of misunderstanding by an assistant. The peas in this row were placed in a furrow two inches deep and covered with about 1 1/2 inches of soil so that a small trench remained which prevented water from draining away readily. The seeds were planted at A-1 and B-1 on July 22, at C-1 on July 23, and at D-1 on July 25, 1960. Immediately after planting, all of the rows were thoroughly sprinkled with water which saturated the soil to a depth of about two inches. Sprinkling was continued every other day until the peas were well sprouted (July 29, 1960) at which time watering was discontinued. After the peas emerged, they were thinned so that none would be closer than four inches to the next plant. Within each row, ten seedlings of uniform size were arbitrarily selected along the distance of the row and marked for close study. The height of each of the ten plants was then measured periodically throughout the growing season.

Several environmental factors were periodically measured within the garden site. Also, recorded data were regularly obtained from the adjacent environmental measurement stations. At the end of the growing season the plants were collected,
Figure 1. Experimental transplant garden at C-1 (10,000 feet or 3,049 meters in altitude). The environment measurement station is in the immediate background. The relationship of the garden and the station was similar at each of the four study areas.

divided into groups of roots, shoots, and fruits; dried and weighed.

Finally the measured heights of the ten plants in each row were averaged, the standard deviation computed, and the results plotted on a graph so that the growth rates, as well as the total heights, could be compared. Soil moisture and air temperature were plotted beneath the pea growth graph so that the growth rate could be readily compared with these environmental factors along a time coordinate.

It is realized that this study involved a relatively small number of plants with treatments arranged systematically, and that without replication of the experimental plots at each altitude one cannot eliminate the possibility of a "row effect" influencing some of the results. Future study will involve the use of "statistical" experimental designs. However, as the results supply additional information on a little studied phase of radioecology—the alteration of a response to irradiation by a method applied after irradiation—a comprehensive review of the study seems justified.

RESULTS

At A-1 (7,300 feet), with the exception of the row which had been treated with 1,000 rads, the irradiated peas showed growth stimulation (Figure 2). It was anticipated that the 5,000 rad-treated peas, being the most severely irradiated, would be the most affected and would grow the least; however, this was not the case. Since, as noted above, these seeds were planted differently from the others, and since the soil moisture was higher in this row throughout the study, it is suspected that the additional soil moisture was sufficient to prevent the anticipated dwarfing effect of the 5,000 rads.

There were no sharp changes in the growth rates of the irradiated and non-irradiated plants during the experiment. The environmental data show that soil moisture was apparently adequate during the experiment, that the temperatures did not drop below freezing, and that the wind was not excessively strong. If the total height of the ten peas is used as an indication, the A-1 experimental plot was more favorable for pea production than any of the other three.

At B-1 (8,500 feet), the growth of the irradiated peas was considerably less than that of the controls; however, the decrease in growth was not proportional to the amount of irradiation (Figure 3). The growth was inversely related to the dose of radiation except at the highest (5,000 rads) level in which case the peas grew slightly better than those with the 1,000 rad dose. In the early stages of growth, while soil moisture was still adequate, the 500 rad-treated peas may have
Figure 2. Experimental station A-1: Summary comparing the average growth of irradiated and non-irradiated pea plants with several environmental factors. Note (1) the apparent growth stimulation of the irradiated plants (with the exception of the 1,000 rad-treated group) over the control group and (2) the variability of the non-irradiated plants was decidedly less than any irradiated group.

shown some stimulation of growth, while those exposed to 5,000 rads of radiation started more slowly and then caught up with the former as the soil dried out.

The environment of B-1 was similar to that of A-1 in most respects, although the wind, soil and air temperatures were somewhat lower. However, the moisture, in relationship to the permanent wilting percentage, showed that the plants were growing under high drought stress throughout much of the experimental period.

The better growth of the 5,000 rad-treated peas at this station cannot be completely explained, but it is known that irradiation frequently increases the leaf thickness (Sparrow and Gunckel, 1936), and the proportion of dry weight to wet weight (Johnson, 1936). Thus, it is possible that this type of radiation effect could lower the transpiration rates of plants and thereby increase their resistance to drought slightly. Under these circumstances the effects of 5,000 rads of radiation would be less deleterious than those of 1,000 rads.

Figure 3. Experimental station B-1: Summary comparing the average growth of irradiated and non-irradiated pea plants with several environmental factors. Note that average growth was inversely related to the dose of irradiation excepting the peas which had been irradiated at 5,000 rads.

At C-1 (10,000 feet), there were no clear-cut differences in the growth of the plants, regardless of their levels of radiation (Figure 4). Approximately one centimeter separated the average total growth of all of the peas, and the variability within each row was nearly as large as that of the entire planting.

The environment record at this elevation was quite different from that of the two lower stations, but the growth character of the peas did not reflect the occurrence of unusually extreme conditions even though several periods of near-freezing temperatures were encountered.

At D-1, the highest elevation (12,300 feet), the plants from non-irradiated seeds or from seeds exposed to low levels of radiation grew at a more rapid rate during their early stages of growth.
than did those exposed to 5,000 rads (Figure 5). This relationship continued until August 16, 1980, when the growth rate of all of the peas, except the 5,000 rad-treated group was reduced. The 5,000 rad-treated group continued to grow at about the same rate and by the end of the experiment showed greater total growth than any of the other groups.

The change in growth rates of the various pea plants occurred at precisely the time of an unseasonal, mid-August blizzard which dropped the air temperatures to 18°F Fahrenheit, the soil surface temperature to below freezing, and which deposited approximately two inches of snow on the ground surface. Peas in all of the rows showed severe frost damage, but the peas in the 5,000 rad-treated group showed less permanent damage. As mentioned above, 5,000 rads of radiation may have produced a morphological or physiological effect that made the plants less sensitive to drought. It is a well-established fact (Levitt, 1986) that sensitivity to frost and to drought are very closely related and the same radiation-produced condition could increase plant resistance to drought in one instance and to cold in another. Another possible explanation is that the 5,000 rad-treated plants which grew more slowly were in a less frost-sensitive stage than the others at the time of the freezing temperatures. Regardless of the cause, under these particular conditions, considering growth rate and total growth, 5,000 rads of radiation produced a favorable effect. This might be regarded by many ecologist as an example of ecological compensation. The detrimental environmental factor (frost) was compensated for by a relatively high level of radiation which may have caused physiological or morphological changes which in turn caused the plant to be less frost sensitive.

The total dry weight comparisons of the shoots and fruit with radiation loads produced the same relationship observed between growth and radiation load at all stations; consequently, these data are not graphed.

CONCLUSION

It was impossible to establish a quantitative evaluation of the effect of a particular radiation dose on the growth of pea plants from irradiated seeds, even though five dose levels of radiation were used in four separate site growth experiments. As may be seen from the graphs (Figures 2, 3, 4 and 5), the comparative growth rates of irradiated and non-irradiated peas differed considerably among
In general, the variability of total pea height was greater among the irradiated than among the control groups, regardless of the regional environment. Although it was anticipated (Higginbotham, 1958), no correlation between variability and temperature was noticeable.

The results of this particular experiment seem to indicate the need for several considerations. Whenever separate investigators attempt to compare data on dose versus growth of plants, it can be assumed that the differential effect of the particular post-irradiation environment and several ecological principles should be considered: (1) A plant growing in a situation where it is near the limit of its ecological amplitude becomes more sensitive to the stimulus of other environmental factors, whether favorable or deleterious. (2) An organism growing in an optimum environment may be less sensitive to deleterious stimuli and may respond differently than in a severe environment. (3) Finally, some environmental factors in particular situations may compensate for harmful effects which might otherwise be produced.

Many practical considerations may be explored regarding environment (radiation included) and plant interaction. One consideration which may merit special attention follows from the study of Schultz et al. (1959), who point out that some plants growing in a strontium-90 contaminated substrate, which have the largest vegetative growth, contain less strontium-90 per gram of dry weight materials than others. It follows that a plant growing in an environment where factors limit or retard its growth may concentrate a much greater load of radioactive nuclides per unit mass, thereby increasing the radiation dose of particular organs. This increase, combined with the action of the 'limiting' or 'stress' environment which produced the concentration, might also cause the plant to increase its radiosensitivity and compound the anticipated effect.

**SUMMARY**

During the summer of 1960, dry pea seeds were irradiated at several levels (0, 100, 500, 1,000, and 5,000 rads). They were then planted in essentially the same manner in each of four experimental plant gardens, located adjacent to regional environmental measurement stations at 7,300 (2,225 meters), 8,500 (2,591 meters), 10,000 (3,049 meters), 12,300 (3,750 meters) feet in altitude on the east slope of the Colorado Front Range west of Boulder, Colorado. Total height of the peas was measured at intervals throughout the summer. These data were then correlated with the environment as determined from the adjacent environmental measurement stations. Comparisons revealed that growth after identical radiation dosages varied much less (dwarfed) to insignificantly greater (stimulated) than that of the controls, depending upon the type of post-irradiation environment.

**ACKNOWLEDGMENTS**

Many persons and agencies have contributed to the success of this study.

The following part-time employees of the Institute of Arctic and Alpine Research made especially valuable field and laboratory contributions: Mr. James Armstrong, Mr. Breck Byers, Mr. Roger Eggberg, Mr. Ronald Foreman, Mr. Andrew Johnson, and Mr. Lewis Pennock.
Dr. Elmer Reminga, statistician of Colorado State University, computed the standard deviations; however, he was not responsible for the experimental design. Mr. James Snow was responsible for drafting the data.

Dr. Bert Tolbert was especially cooperative and offered many helpful suggestions in the preliminary stages of this study and was always an enthusiastic consultant.

Dr. Robert Crocker, Dr. Edith Dahl, Miss Linda Ellison, Dr. John Marr, Mr. Mark Paddock, Dr. Hugo Rodeck, and Dr. Olwen Williams each read and contributed helpful suggestions concerning this manuscript.

Finally I should like to thank the U.S. Atomic Energy Commission for financial support for this research under contract number AT(11-1) 435 between the Commission and the University of Colorado.

REFERENCES


NATURAL RADIATION EFFECTS OF VERTEBRATE ANIMALS INHABITING THE URANIUM AREAS OF SOUTHEASTERN UTAH

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Brigham Young University, Provo, Utah

INTRODUCTION

For several decades, scientists have been aware of a higher-than-average external radiation in various areas throughout the Upper Colorado River Basin. Although most of the deposits with radioactive minerals are deep, a few are near enough to the surface to provide for higher-than-average external gamma and beta radiation. Many of the subsurface deposits are relatively small in area; there are, however, areas of sufficient size to allow an ecological study of some of the vertebrate populations inhabiting them.

The Upper Basin consists primarily of sedimentary deposits laid down not only by water, but also, perhaps, by wind erosion as well. The geological history provides one with an insight into several apparent crustal uplifts, as well as submergences.

Since, or in conjunction with, the last major uplifts, there has been considerable faulting and also much doming of the landscape by laccolithic intrusions. These, plus the gorges made by the streams, have provided one of the roughest areas in the United States.

Figure 1. Upper Colorado River Basin study areas.

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In general, we must consider the Upper Colorado River Basin, except for the higher mountains and plateaus, a steppe desert. The vegetation is sparse and, in general, characteristic of the upland deserts of western North America. Flowing through these areas are the numerous tributaries of the Colorado and Green Rivers. Because the basin is surrounded by high plateaus and mountains, the streams are generally fast-flowing and extend as strips of lush vegetation through an otherwise arid terrain. Furthermore, the streams have cut through the relatively soft sedimentary strata to produce deep gorges. This has had the effect of lowering the water table and increasing the aridity of the intervening areas. Therefore it is important to realize at the outset that those areas under our immediate observation are semi-deserts. Because of the reduced vegetation an easier observation of the fauna and flora has been possible. However, the general aridity has reduced the numbers of individuals in these populations, which directly affects our ability to secure the large number of individuals needed in our variation studies.

The present study was initiated on October 1, 1959, although actual field work in the Upper Basin did not begin until the spring of 1960.

Four study areas are being investigated (Figure 1). Two are in the San Rafael Swell in east Emery County. The first of these is in the Temple Mountain District. The second is 35 miles north in the Manie Stover Incline District. A third area is in the Yellow Cat District of central Grand County and the fourth in Indian Canyon of northwestern San Juan County.

Ecologically, the San Rafael Swell areas are in juniper with scattered small trees (junipers, Juniperus utahensis; mountain mahogany, Cerocarpus intricatus; and desert ash, Prunus arctostaphylos). Sage (Artemisia spp.) and saltbrush (Atriplex confertifolia) are a few of the low-growing brushes. Grasses are predominant (Stipa speciosa, S. columbiana, Hilaria jamesii, Agropyron spicatum, Sitanion rystrix, Oryzopsis hymenoides, Distichlis stricta, Hordeum jubatum, and Aristida longiseta). Indian Canyon is a rather broad valley in which the overburden has been eroded to expose on each side of the stream bed the ore-bearing sediments. The vegetation is varied; along the stream are the usual cottonwoods (Populus fremontii), willows (Salix spp.), sedges (Carex spp.), and grass (see above); on the upper bank and the gentle slope to the canyon wall a growth of silt and sage brushes predominates.

Within these areas we are attempting to discover (1) the average gamma radiation at ground level for each area, (2) gamma radiation at localized areas within each major area, and (3) an approximation of the radiation within a home range of the several animals being studied. The latter is proving to be a real challenge. We hope to solve it by means of a small dosimeter correlated with the basic counts established by a scintillation counter and geiger counters.

ANIMALS CONSIDERED

Consideration has been given primarily to the lizards of each area, although we are collecting a series of the small mammals as well.

In the first year of study, emphasis was placed on the movements of the various species in the hope that we might ascertain the extent of their movements within the area. If the vertebrate species under consideration range widely and regularly move into areas where there is considerable variation in the amount of external gamma and beta radiation, then we might expect different results than if the home range is smaller and has more uniform physical and biological factors. The testing for home range has been done primarily in the Temple Mountain District, where we have marked, by toe clipping, over 300 lizards-Uta stansburiana, Sceloporus undulatus, and Cnemidophorus tigris septentrionalis. In each case, the data from the recaptured specimens indicate that these species do not have an extensive home range during the course of one summer. Uta stansburiana appears not to move for more than ten to 25 yards in its normal foraging movements. One specimen is known to have moved 50 yards, this being the greatest distance thus far recorded for this species. In both of the other species, a larger home range is indicated. Inasmuch as both Sceloporus and Cnemidophorus are much larger than Uta, it appears that the home range in these species is proportionate to the size of the lizard. In both Sceloporus and Cnemidophorus at least a 50-yard radius is indicated. One of the latter, with data from six recaptures, suggests an even larger home range.

Unfortunately, the rodent population in this area crashed the first winter, and during the summer of 1961, the only mammals observed in the entire area were a few squirrels (Sturnia quadrivittata). All of the wood rats (Neotoma lepida), antelope ground squirrel (Ammospermophilus leucurus), and deer mice (Peromyscus spp.) were presumably eliminated by disease.

To date our investigation of population variation is being done with those species which are widespread throughout the Upper Basin. At present our greatest concern is with those populations inhabiting areas where there is a ground radiation of 20 or more microroentgens per hour. Actually some small areas within the larger areas under study have a surface radiation of over 100 microroentgens per hour. With such variation in the level of surface radiation, one of our problems is to determine the approximate radiation dose received by each animal during a 24-hour period.

In the vicinity of each area, we plan to examine the populations in areas where the surface radiation is less than 20 microroentgens per hour. Near the Temple Mountain area is a population of lizards inhabiting a small valley in which the surface radiation is less than 20 (17 to 18) microroentgens per hour. As data become available, these various populations will be analyzed on the basis of (1) total variation of a single character, (2) total variation of all characters considered, and (3) direction of the curve, e.g., to the left or right, or if the curve is normal. Our prime consideration is to discover if there is a greater degree of variation in those populations where ground radiation exceeds 20 microroentgens per hour and if so, to what extent. Unfortunately, our data are incomplete and must await analysis at a future date.

ACKNOWLEDGMENTS

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COMPARATIVE ECOLOGICAL STUDIES OF ANIMALS AT THE NEVADA TEST SITE

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Brigham Young University, Provo, Utah

INTRODUCTION

In 1959 the Department of Zoology and Entomology of Brigham Young University undertook a comparative ecological study of the native fauna at the Nevada Test Site in order to investigate the effects of nuclear detonations on the animals. This was one of three separate projects operating in a coordinated manner at the test site on the biological aspects of environmental research. New Mexico Highlands University is studying effects of nuclear testing on desert plants, and the University of California at Los Angeles is studying biological availability of radionuclides to both plants and animals. Our objectives are to determine kinds, populations, geographical and seasonal distribution, migration, home range, and other habits of native animals. One additional objective is to determine tissue changes, if any, in native animals collected from areas contaminated with radioactivity compared with animals in relatively non-contaminated areas. Inasmuch as no pre-test biological surveys at the test site were made, basic ecological data are being obtained on this project. From these data it is intended that the effects of nuclear testing on native animals in this desert area may be determined by extrapolation from contiguous undisturbed areas.

STUDY AREA

The Nevada Test Site is in southeastern Nye County, Nevada, 65 miles northwest of Las Vegas. The area is about 40 miles long and 17 miles wide, comprising a total of about 500 square miles. There are three major valleys bordered by hills and ridges of moderate relief. The southernmost valley, Frenchman Flat, and the northernmost valley, Yucca Flat, are undrained basins, each possessing a playa at elevations of approximately 3,200 and 3,900 feet, respectively. Jackass Flats to the west lies at an elevation intermediate between the two major valleys and is not a closed drainage basin.

Frenchman and Jackass Flats are predominantly occupied by plants typical of the Mojave Desert complex (Southern Desert Shrub Community), such as Larrea divaricata Cav., Franseria dunosa Gray, Yucca brevifolia Engelm., Y. schidigera Roegli., and Lycium pallidum Miers (Figures 1, 2, and 3). Yucca Flat has characteristics of both the Mojave and Great Basin (Northern Desert Shrub Community) deserts, possessing plants such as Gravia spinosa (Hook.) Moq., Atriplex confertifolia (Torr. and Frem.) Wats., Kochia americana Wats., Lycium andersonii Gray, and Colocynthe ramosissima Torr., with scattered areas of Yucca and Larrea (Figures 1, 4, and 5). The valleys and high mesas encroaching on the test site from the north possess plants typical of the Great Basin flora, such as Artemisia tridentata Nutt., Pinus monophylla Torr. and Frem., Juniperus utahensis (Engelm.) Lemmon, and Quercus gambelii Nutt. (Figure 6).

PROCEDURES AND RESULTS

Study sites have been established in the predominant plant communities in all three valleys, although greatest emphasis is being given Yucca Flat where most nuclear detonations occurred (Figure 7). Quadrats of 15.6 acres each with trapping stations spaced at 75-foot intervals are
being studied in undisturbed Lycium (matrimony vine), Larrea (creosote bush), Gravia-Lycium (hopsage-matrimony vine), Atriplex-Kochia (shadscale-gray molly), Coleogyne (blackbrush), and mixed plant communities. Similar studies have been established in areas disturbed by nuclear tests in Gravia-Lycium communities where most of the nuclear devices have been detonated. Other studies include single-line transects with collecting stations varying from 30 to 264 feet apart.

Methods of collection of mammals include modified Young, live-catch rodent traps, Museum Special snap traps, Victor-Oneida jaw traps, and sunken can traps. Reptiles are collected primarily with sunken cans, birds by shooting and Japanese mist nets, and invertebrates by use of sunken cans, various types of nets, and Berlese funnel extraction.

A complex of several of the predominant plants listed above.

Mammals are marked by a combination ear and toe clip method, lizards by toe clipping, and birds by numbered leg bands. Only experimental studies have been undertaken thus far with marking of invertebrates.

Three main phases of operation and processing of animals and data have been followed. Field operations have involved the collection, marking, and observation of animals and animal activities. Data for each specimen include items such as locality, date, plant community or host, stage of development, sex, population, and other information which contributes to an understanding of specific biology. Laboratory operations involve the preservation and preparation for identification of specimens by specialists. All data for identified specimens are recorded on International Business Machine (IBM) punch cards for analysis by an IBM 650 computer.
Data for all specimens are recorded, and most specimens collected are preserved except those which are marked and released for activity, longevity, and other related studies. As fast as specialists make specific determinations for collected specimens data for these and released specimens are entered on IBM punch cards. The only species of animals receiving emphasis at present are those which are relatively and seasonably abundant, and have broad ecological and geographical distribution on the test site. These include species of scorpions, spiders, grasshoppers, crickets, ants, beetles (Tenebrionidae and Curculionidae), flies (Diptera), lizards, birds, and mammals (rodents). For these groups considerable data have been accumulated on kinds, relative abundance, seasonal and geographical distribution, as well as some range of movement.

Difficulty in identification of the vast numbers of individuals and kinds of invertebrates obviously delays their analysis. Another factor affecting final analysis of the invertebrate fauna is that a considerable number of undescribed species have been found. Before these can be discussed, their descriptions must be published.

Investigations to date show a relatively rich

| Animal group | Total number of species at the site | Atriplex-Kochia | Coleogyne | Larrea | Lycium | Gravida-Lycium
<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
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<td>Grasshoppers, crickets, etc.</td>
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<td>9</td>
<td>11</td>
<td>10</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Ants</td>
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<td>8</td>
<td>7</td>
<td>4</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Beetles</td>
<td>32</td>
<td>5</td>
<td>6</td>
<td>10</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>Lizards</td>
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<td>2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
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<td>0</td>
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<td>4</td>
<td>1</td>
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<td>Birds</td>
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<td>7</td>
<td>12</td>
<td>12</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Mammals</td>
<td>34</td>
<td>12</td>
<td>11</td>
<td>11</td>
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<td>Total</td>
<td>341</td>
<td>43</td>
<td>51</td>
<td>63</td>
<td>33</td>
<td>29</td>
</tr>
</tbody>
</table>

1To August 1, 1961. Other numbers in table include data only to December 31, 1960. Collecting commenced in August, 1959.

<table>
<thead>
<tr>
<th>Species</th>
<th>Atriplex-Kochia</th>
<th>Coleogyne</th>
<th>Larrea</th>
<th>Lycium</th>
<th>Gravida-Lycium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cricket: Trimerotropis palidipennis</td>
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<td>.17</td>
<td>.11</td>
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<tr>
<td>Ants: Myrmecocystus</td>
<td>.03</td>
<td>.02</td>
<td>.01</td>
<td>1.0</td>
<td>.07</td>
</tr>
<tr>
<td>Mexicanus</td>
<td>.03</td>
<td>1.0</td>
<td>.06</td>
<td>.03</td>
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</tr>
<tr>
<td>Wasmannomyrma</td>
<td>.04</td>
<td>.16</td>
<td>.02</td>
<td>.58</td>
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<td>P. californicus</td>
<td>.08</td>
<td>.22</td>
<td>.58</td>
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<td>.01</td>
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<td>.10</td>
<td>.13</td>
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<td>.50</td>
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<td>.23</td>
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<td>E. nigripennis</td>
<td>.02</td>
<td>.01</td>
<td>1.0</td>
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</tr>
</tbody>
</table>

1.0 indicates that more specimens of the species were collected in that specific plant community than in any other community. Fractions indicate proportionate numbers found in other communities.
fauna at the test site. As may be expected, the greatest total number of species has been found in areas disturbed by nuclear tests (Table 1). Second greatest number of species was found in the Larrea community which may be typical of the Mojave influence.

With respect to certain commonly occurring representative species, the greatest numbers of individuals of invertebrates were found in disturbed areas (Table 2). However, this same coordination did not occur with the mammals as a group, for apparently their abundance is influenced less by the disturbance factor (Table 3). Range of movement of some of the small rodents is influenced by disturbance, however. With reference to kangaroo rats of two species, rats in disturbed areas ranged from three to ten times farther than those in undisturbed communities (Table 4).

It is assumed that such differences resulted from extreme changes of the biotic communities as affected by the physical effects of nuclear detonations rather than by initial or low-level residual radiation. Similar changes of the plant community and consequent reactions of the animals might be expected as a result of range fires, overgrazing or other disturbance of a given area.

ACKNOWLEDGMENTS

Specialists who have assisted in identifying specimens are, for the vertebrates: C. L. Hayward and W. W. Tanner, Brigham Young University, Provo, Utah. For the invertebrates: A. H. Barnum, Dixie College, St. George, Utah; E. Johnson, University of Utah, Dugway, Utah; A. C. Cole, University of Tennessee, Knoxville; W. J. Gertsch, American Museum of Natural History, New York, N. Y.; M. H. Muma, University of Florida, Lake Alfred; R. V. Chamberlin, J. J. Mulfick, C. F. Edmonds, and A. Grundmann, University of Utah, Salt Lake City; C. J. Drake, U. S. National Museum, Washington, D. C.; H. F. Bowden, Canada Department of Agriculture, Ottawa, Ontario; D. M. Allered, D. E. Beck.

### Table 3. Relative abundance index of some representative mammals in different plant communities at the Nevada Test Site, 1959-1961.

<table>
<thead>
<tr>
<th>Species</th>
<th>Atriplex-Kochia</th>
<th>Coleogyne</th>
<th>Larrea</th>
<th>Lycium</th>
<th>Grayia-lycium</th>
<th>Grayia-lycium</th>
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<tbody>
<tr>
<td></td>
<td>Undisturbed</td>
<td></td>
<td></td>
<td></td>
<td>Atomically</td>
<td>disturbed</td>
</tr>
<tr>
<td></td>
<td>Atriplex-</td>
<td>Coleogyne</td>
<td>Larrea</td>
<td>Lycium</td>
<td>Grayia-lycium</td>
<td>Grayia-lycium</td>
</tr>
<tr>
<td>Antelope squirrel</td>
<td>Ammospermophilus</td>
<td>0.09</td>
<td>1.0</td>
<td>0.64</td>
<td>0.86</td>
<td>0.56</td>
</tr>
<tr>
<td>Kangaroo rats</td>
<td>Dipodomys</td>
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<td>0.03</td>
<td>0.84</td>
<td>0.31</td>
<td>0.03</td>
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<tr>
<td></td>
<td>merriami</td>
<td>1.0</td>
<td>0.83</td>
<td></td>
<td>0.27</td>
<td>0.11</td>
</tr>
<tr>
<td>Grasshopper mouse</td>
<td>Onychocnemis</td>
<td>0.45</td>
<td>0.86</td>
<td>0.15</td>
<td>0.25</td>
<td>1.0</td>
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<tr>
<td>Deer mouse</td>
<td>Peromyscus</td>
<td>0.08</td>
<td>1.0</td>
<td></td>
<td>0.12</td>
<td>0.04</td>
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<tr>
<td>Pocket mice</td>
<td>Perognathus</td>
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<td>0.01</td>
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<td></td>
<td>formosus</td>
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<td></td>
<td>P. longicaudis</td>
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</tr>
</tbody>
</table>

1.0 indicates that more specimens of the species were collected in that specific plant community than in any other community. Fractions indicate proportionate numbers found in other communities.

### Table 4. Range of movement of two species of kangaroo rats, in different plant communities, Nevada Test Site, 1959-1961.

<table>
<thead>
<tr>
<th>Species</th>
<th>Atriplex-Kochia</th>
<th>Coleogyne</th>
<th>Larrea</th>
<th>Lycium</th>
<th>Grayia-lycium (Salsola invasion)</th>
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<tbody>
<tr>
<td></td>
<td>Undisturbed</td>
<td></td>
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<td></td>
<td>Atomically disturbed</td>
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<tr>
<td></td>
<td>Atriplex-Kochia</td>
<td>Coleogyne</td>
<td>Larrea</td>
<td>Lycium</td>
<td>Grayia-lycium (Salsola invasion)</td>
</tr>
<tr>
<td>Dipodomys</td>
<td>Male</td>
<td>323.70</td>
<td>256.37</td>
<td>28.02</td>
<td>29.36</td>
</tr>
<tr>
<td></td>
<td>Female</td>
<td>357.08</td>
<td>56.88</td>
<td>80.54</td>
<td>39.31</td>
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<tr>
<td>Dipodomys</td>
<td>Male</td>
<td>341.23²</td>
<td>256.37</td>
<td>188.31</td>
<td>301.36</td>
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<tr>
<td></td>
<td>Female</td>
<td>357.12</td>
<td>223.12</td>
<td>202.11</td>
<td>193.00</td>
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</table>

Top figures: average straight-line distance (in feet) between the most widely separated points of capture + one standard error of the mean.  
Middle figures in parentheses: sample size (number of individuals).  
Bottom figures: Standard error of the mean.
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