H. Comment

The description above considers only a part of the work of the NAEG since it relates only to the actinides. Much was done also with fission products. A broader review can be seen from the report listing and contents in note 2.

As indicated earlier, the question was asked as to whether or not the work of NAEG on the safety-shot sites had not reached a logical termination point. Wallace and Romney (1978) could muster numerous cogent reasons for continuation, and this author agrees that many questions remain unanswered, especially when really long-term behavior is to be considered. However, the intense pressures of the weapons test fallout litigations (chapter 12) and other aspects of more dramatic and urgent proportions have siphoned off, at least temporarily, the will and resources to do what really should be done, even though we have the opportunity.

IV. Fission Product Field Releases

The possibility of release of fission products from a nuclear reactor stimulated much interest in gaining knowledge of the fractions of the total inventory that might be released, the chemical and physical form of the released materials, and their potential biological effects. We have already encountered many aspects of this problem. There were reasons to expect that many of them might differ appreciably from the fission products in fallout from weapons tests, especially worldwide fallout. Some of the potential contrasts were pointed out in earlier chapters (e.g., chapters 10, 11, 12). Yet, the newly developing nuclear industry could hardly be expected to do more than calculate. A staged meltdown of a complex and fully instrumented reactor could hardly be counted upon! Luckily, the same question arose in connection with plans for development of a nuclear powered aircraft. The U.S. Air Force went far enough with plans for such a development that they determined that some sort of field studies had to be done. These provided some of the types of data needed in the broader context.

Under the aegis of the Air Force Special Weapons Project, and as part of the "Aircraft Nuclear Propulsion Project," tests were planned with objectives broadly similar to those of the plutonium safety shots we have just reviewed. These were handled largely through the Air Research and Development Command at Kirtland Air Force Base at Albuquerque, New Mexico, and its contractors. There was particular collaboration from the General Electric Company for fuel element and hot-cell aspects; the University of Rochester for biological work; the Idaho Operations Office of the AEC for meteorology, health physics control and site survey, and ecological sampling; the Air Force Special Weapons Center for many logistic and specialized functions; and Convair-Fort Worth. It was determined that the most reasonably realistic surrogate for a potential accident involving an operating reactor propelling an aircraft was to melt down fuel elements and release their contained fission products under known conditions. Questions asked were: (1) release percentages, (2) particle size and size distribution, (3) atmospheric diffusion, (4) deposition on a variety of surfaces, and (5) uptake by living animals and plants, including possible biological effects.

The tests took place primarily at the AEC's National Reactor Testing Station near Idaho Falls, Idaho, but a few were conducted at the Dugway Proving Grounds in Utah. Convair-Fort Worth, the potential builder of a nuclear-powered aircraft, conducted the tests physically under direction of the Air Force. The role of the University of Rochester was much as it was for the plutonium work. A fairly elaborate set of facilities for animals and biological work was built at Idaho Falls. All biological aspects, except certain ecological measurements, were the responsibility of the Rochester group. R. H. Wilson and R. G. Thomas were again key planners and operators for the biological program. They were joined by R. Lie and G. A. Smith from Rochester; B. B. Boecker, Rochester and later Air Force and Convair-Fort Worth; J. L. Terry from the Air Force; and L. J. Signeur who did behind-the-scenes work. Very satisfactory facilities were developed by modification of three standard Air Force truck trailers. Since these represent something of a climax in the development of such field facilities for biological work and they were very versatile, interior views of the laboratory and animal trailers are shown as figure 14.3A and B.[a]

These tests were performed in the period July-October 1958. Unlike the work with plutonium, data for the total activity of fission products, the gamma spectra, and, to a degree, the apportionment of activity among the various elements could be determined relatively quickly. Indeed, the results of one test could be used to modify plans for subsequent tests. Also, unlike the work with plutonium, many variables could be introduced in the series and multiple tests accomplished. Besides meteorological conditions, the age of the fuel element, i.e., "green" or "aged" according to the time in the reactor, was a prime variable.

The exposures were carried out by fast melting of the fuel elements from a reactor in a special induction furnace at ground zero. The plume migrated down and across an array of air sampling instruments and animals (animals were not used in all tests). A plume of visible smoke was released immediately preceding and following the fission product release and the plume photographed by ground and aerial cameras. Also, a fluorescent nonradioactive tracer was released to simulate and measure the dispersal characteristics.

The reports of the biological aspects of this work are, primarily, three University of Rochester Atomic Energy Project reports entitled, respectively, *Field Studies of Fission Product Inhalation Parts I, II, and III* (Thomas et al. 1959; Wilson 1959; Thomas and Wilson 1959) and two large reports from the Air Force Special Weapons Center (ANP 1959, 1960). However, there were also Idaho Operations Office reports that gave full details of the physical phenomena (see, e.g., Bunch 1966).

These were relatively short-term experiments. The endpoint, both biologically and physically, was deposition. Few data extend beyond ten days after the release except for two dogs that were placed in metabolism cages and followed for fifty days, and there were some data on tissue content at 150 days or more. Major emphasis was placed on initial deposition and, thus, rapid retrieval of the animals from the field. Evidently the meteorological conditions were sufficiently reliable for the first Fission Product Field Release Test (FPFRT) that no special efforts were needed to provide for quick movement of the animals, as we saw in Operation Roller Coaster. Thus, the array was fixed within a sixty-degree sector, and experimental arcs were at 100, 200, 400, 800, 1,600, and 3,200 m and about 5 mi downwind of the release point. Animals were placed at the

(a) These trailers met their purposes so well that they served for several years as additional (and isolated) laboratory space behind the University of Rochester Atomic Energy Project.

FIGURE 14.3A. (Left) Interior view of trailer utilized for laboratory work, particularly radioactivity counting in the Fission Product Field Release Tests at the National Reactor Testing Station at Idaho Falls. (Courtesy of Wilson 1959.)

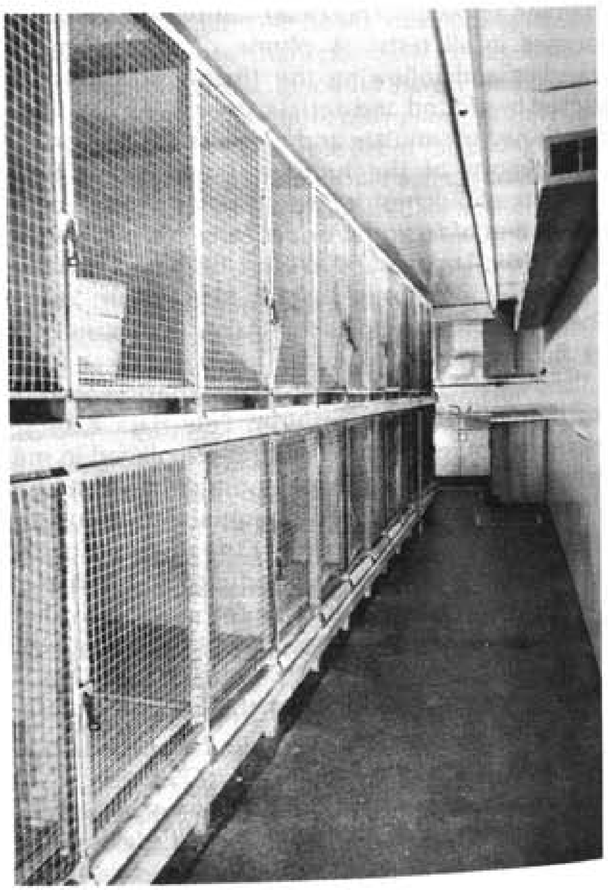

FIGURE 14.3B. (Right) Interior view showing full length of animal trailer used in the Fission Product Field Release Tests at the National Reactor Testing Station. Beyond the dog cages at the far end is a furnace-air-conditioner, water heater and storage facilities. Normally cages for rats were mounted on the right wall. (The usual practice of not mixing species in animal care facilities was not employed because of the relatively short duration of the experiments.) (Courtesy of Wilson 1959.)

100-, 200-, 400- and 800-m stations and as close as possible to the air sampling instruments for those locations. The animals were white rats and mongrel dogs.[a]

In subsequent operations, a track of perforated steel was laid down, and the animals were placed in wagons that could be moved by pulling on long ropes. This was indeed a prelude to the procedure used at Operation Roller Coaster.

Despite the predictions from experience, the first tests in the fission product release series were done without special precautions to minimize ingestion of materials deposited on the fur or around the noses of the animals.

In the trials with rabbits, reported in the Aircraft Nuclear Propulsion report (ANP 1959), scalp activity and lung activity were reported. In general, they correlated well with each other with distance from the shot release. In the early Rochester experiments, the animals were in open cages, and deposition in the gastrointestinal tract was unrealistically high. Alteration of the exposure cage design to minimize licking of the fur, anesthetizing the animals, and changing the methods of sacrifice brought the gastrointestinal-tract-to-lung ratios from more than thirty to one to less than one to one. However, care had to be exercised not to alter significantly the respiratory functions of the animals, and anesthesia was not used routinely. Changes in the contours of the exposure cages (primarily those for the rats), muzzling the dogs, and great care not to introduce artifacts at the time of collection were the most useful ways to avoid unwanted ingestion of the fission products. The nuances of these and other details of methodology are described by Thomas et al. (1959) and Wilson (1959).[b]

It turned out that the "aged" fuel elements released an aerosol composed primarily of cesium. Indeed, about 83% of the premelt cesium was lost from the elements. Counting and dose calculations were relatively easy. The "green" fuel elements produced more of a mixture, but iodine predominated. In fact, the results were routinely reported in two parts, iodine and all other isotopes. The latter category had a half-life greater than thirty days. It was inferred that the iodine was largely in an uncombined form. Another difference between the two forms of elements was seen in the ratio of external contamination to lung. For the releases from green elements, this ratio (for iodine) was ten times that seen for cesium from the aged fuel elements. Thus, a difference in physicochemical properties (solubility?) undoubtedly existed. For these reasons, the results for the two forms of elements were reported separately.

Deposition (median) in the lower respiratory tract of rats and dogs is summarized in the following data modified from Thomas et al. (1959):

aged elements:	green elements:
54 rats = 28%	116 rats = 33%
12 dogs = 24%	18 dogs = 35%

On this basis, the combined figure for deposition in rats was taken as 33% and for dogs 31%. What is not shown is the rather large range of variation of the figures. Nevertheless, the median figure for deposition in the lower respiratory

(a) Some of the ANP documents mention rabbits for some of the early tests. It is not clear who had responsibility for these, presumably not the University of Rochester. They appear to have been used only for measurements of external contamination. (Wilson [1984] suggests that this refers to the numerous indigenous jack rabbits.)

(b) The first test described by Thomas et al. (1959) released so little activity that no conclusions could be drawn.

tract was not seriously at odds with the usual figure, 25%, derived from the then-extant lung model (see chapter 16). Total deposition, i.e., deposition in (and on?) the whole animal, showed a median of 67% without much difference between aged or green fuel elements. For several reasons, the authors prefered to utilize a total deposition figure of 75% for hazard-evaluation purposes.

Tissues were analyzed in some instances for periods up to over 150 days after exposure. In addition to gastrointestinal tract (sometimes done in segments), lung, kidney, muscle, and blood were analyzed (the latter only when samples of 120 mℓ or more were available). The results are outlined below:

1. In the work with green fuel elements, stomach appeared to contain much more iodine than any other portion of the gastrointestinal tract or any other organ. The ratio of iodine to long-lived fission products was about three for kidney, lung, and small and large intestine, but it was about nine for stomach. Air-filter samples were like all organs except stomach. Thus, some selective accumulation in stomach must be considered.
2. Lung contents (total count) fell considerably less rapidly with time than did stomach, while kidney and lung were roughly comparable.
3. The time course and element ratios on the average air filter and in lung were roughly comparable.
4. Esophagus was high compared to lung or gastrointestinal tract after exposure to the aged fuel elements.
5. There was essentially no cesium in muscle, even from experiments with the aged-fuel-element release.
6. In general, radionuclides from the aged elements, e.g., cesium, were more slowly transported than those from the green elements , e.g., iodine.
7. Thyroid uptake was analyzed in some of the dogs, but only after *intravenous* injection.

The two dogs placed in metabolism cages for fifty days showed unexpectedly almost equal amounts of gross activity in urine and feces over the entire fifty-day period. This indicates the presence of insoluble radioactive material in the lung that was being gradually fed to the gastrointestinal tract by pulmonary clearance processes. Since the exposure came from what was considered a green fuel element, this implies that the mobile iodine was not the only element present.

The work at Dugway is described in the second Convair report (ANP 1960). The fallout patterns at Dugway are described therein for eleven releases using fuel elements of the type planned for the ANP reactor. Exposure of animals is indicated as having taken place, and the statement is made that the results would be reported by the University of Rochester. However, no such reports appeared. It is understood (personal communications from the Rochester group) that the biomedical data obtained could not be used.

The purpose of these tests was hazard evaluation. What was found that might modify analyses of hazard derived from laboratory experiments?

1. The age of the fuel elements makes an obvious difference in the elements of importance. This could have been determined from the laboratory work. However, the difference by a factor of ten in deposition velocity could not have been guessed.
2. The constancy of urinary to fecal excretion rates, seen in the metabolism dogs, was not expected.

3. Gross fallout measurements can give misleading results for estimation of body (i.e., lung) uptake. Individual elements must be considered in part.

Unfortunately, the number of animals in this work is small, and ranges of variation are large. A larger series might have made the conclusions more certain. Nevertheless, the work was a worthwhile check of field versus laboratory with, as in other cases, significant differences noted.

In a broader sense, it may be asked if these biomedical tests discouraged the further development of the nuclear-powered aircraft, particularly from the standpoint of potential environmental contamination. This seems unlikely. It is true that the longer-lived fission products could assume greater importance in the operation of such devices than in fallout from weapons tests. Yet, nothing in the reported results indicated the presence of problems so drastically different from the predictions that the project should be discontinued. It seems more likely that protection of the crews by shielding and by wide separation from the reactors presented more serious biomedical problems than those of environmental contamination. Nevertheless, the public reaction to a device that had to discharge some fission products to the atmosphere in normal operation and that could not be made heavy enough to contain, for certain, the enormous radioactive inventory in the event of an accident was likely to be quite negative. Very real advantages, even over and above the potential for very long flight times, had to present themselves.

In any event, the ANP project wound down, and there were no more biomedical tests. There were, however, related ones in the projects Kiwi, etc., as we reviewed in chapter 9 and will consider again briefly later in this chapter.

V. Project Plowshare

A. Development of the Plan

Project Plowshare was one of the most ambitious and extensive facets of the Atoms for Peace Program.[a] It envisioned the use of nuclear explosives for relatively quick and inexpensive (in comparison to conventional means) digging of harbors; for releasing large stores of natural gas or petroleum trapped underground in impermeable strata; for transportation construction projects requiring the "moving of mountains"; waterways; even to the digging of a new canal from the Atlantic to the Pacific across the isthmus of Panama or adjacent thereto.[b] It was a visionary project built around Isaiah's ancient prophecy,"and they shall beat their swords into plowshares."

Several books were written directly about the ideas of Project Plowshare. Two are cited for the reader's convenience: a semipopular description by Ralph Sanders, Washington, D.C., with a foreword by former AEC Commissioner Willard F. Libby (Sanders 1962), and a more technical treatise by Edward Teller and collaborators (Teller et al. 1968). There were, in addition, many special

(a) See especially chapter 20 and references given therein, as well as passing mentions in other chapters for description of the Atoms for Peace program and its origins.

(b) Other possible uses were in mining; the production of power by utilizing the long-lasting heat from a nuclear detonation in deep rock; the production of isotopes and of chemicals that could be extracted; and various scientific applications pertinent to neutron physics, geophysics, and space physics.