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To: Colonel K. D. Nichols

From: Joseph G. Hamilton, M. D.

Subject: RADIOACTIVE WARFARE

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The use of fission products as a military agent presents a number of very novel considerations which distinguish this potential weapon from chemical tools of war, such as mustard gas, lewisite, phosgene, et cetera. The major differences between chemical and radioactive poisons may be divided into the following principal categories. One; the quantity of radioactive poison required to produce lethal effects can be measured in the range of micrograms while in the case of chemical agents, there is usually required tons to hundreds of milligrams to produce comparable biological damage. Two; it is impossible to detect the presence of radioactive poisons without the aid of suitable electrical devices such as Geiger counters, ionization chambers, electroscopes, et cetera. In other words, the radiation from radioactive materials cannot be detected by touch, smell, taste, et cetera. Three; the biological damage produced by such radiations has a high degree of latency in that even with lethal dosages, the full effects may not appear for intervals extending from days to the order of several months. In addition, complete recovery from sub-lethal injury may not occur in a considerable portion of individuals exposed and this factor of chronic injury may be expected to occur in a much higher proportion of subjects than might be expected from sub-lethal chemical injuries from most, if not all, of the known war gases. Four; radioactive poisons may persist in an infected region for extremely long periods of time, if the material injected has a sufficiently long half-life. Five; removal of radioactive materials once they have become deposited on soils, buildings, roads, et cetera, will be in most instances so difficult that for all intents and purposes, decontamination may be considered an almost insurmountable problem.

The fission products can be employed either against personnel, both civilian and military, or they may be used to impair if not destroy the use of agricultural areas for the purpose of producing food crops. These materials can produce injury to man, as well as animals. Injury can arise from several different mechanisms, namely, inhalation, ingestion, and external irradiation. Following absorption into the body the majority of the longer-lived fission products, whose half-lives extend from the order of two weeks to many years, are accumulated and tenaciously retained in the skeleton. There, they produce internal irradiation of the very sensitive bone marrow and even rather trivial amounts can produce lethal effects. The inhalation of finely suspended particles such as dust or smoke, containing a mixture of the longer-lived fission products is attended by a significant percentage of inhaled material being retained in the lungs for intervals extending to as long as a year. A variable but significant fraction of the fission products initially retained by the lungs following inhalation will be absorbed through the lung tissues into the blood stream and then be deposited within the skeleton. In general, the damage to the lungs will be greater than to the blood forming tissues within the bone marrow. However, it is perfectly feasible to prepare radioactive smoke of such a character so that the injury to the bone marrow will predominate over pulmonary damage. The oral ingestion of many of the fission products is followed by a rather trivial degree of absorption from the digestive tract. If an unseparated mixture of long-lived fission products is employed, less than from 3% to 10% will be absorbed through the digestive tract. Approximately half of the material so absorbed will become deposited within the skeleton. External irradiation arising from fission products spread over a large area, presents another important aspect of the problem of radioactive warfare. Inasmuch as both beta and gamma rays are emitted from the fission products mixture, superficial as well as penetrating damage may occur. In the main, the gamma rays will be the more ominous of the two radiations insofar as lethal injury to personnel is concerned. From 400 to 600 roentgens is believed to constitute an acute lethal dose of penetrating gamma rays for an adult human. Severe and slow healing lesions of the skin and subcutaneous tissues will occur following 3,000 to 6,000 roentgens of beta irradiation of an energy range from 250,000 to 2,000,000 volts. Due to the fact that beta rays are relatively easily absorbed, a considerable diminution of that effect will arise from absorption in clothing, shoes, et cetera.

The contamination of soils presents another aspect of the destructive potentialities of the fission products as a military agent. The accompanying report on the behavior of fission products and soils elucidates this issue to a considerable degree. Briefly, the situation is that most of the long-lived fission products, because of their chemical properties become extremely firmly fixed on to soil particles. Plants growing in such contaminated soils have the potentiality of accumulating to a very high degree, a considerable fraction of the fission products that are fixed upon the soil particles. Inasmuch as this accumulation by the plants occurs chiefly in the roots which are relatively sensitive to radiation, it can be readily appreciated that significant areas of ground may be made essentially sterile insofar as their agricultural use is concerned. In addition, there is a corollary problem which arises, namely, the assimulation of certain fission products, notably cesium and strontium in the leafy portions of plants. Conceivably, food crops growing in soils contaminated below the level required to kill plants could result in the poisoning of the plant products insofar as animal or human consumption is concerned.

The quantity of given fission product mixture that is required to produce damaging effects, whether it be in humans or plants, depends upon the age and composition of the fission product mixture employed. Obviously, there is almost an unlimited series of numbers which could be given for such amounts since there are not only many elements involved in the fission product series but also the half-lives of the individual elements produced in fission extend from seconds to centuries. However, as a practical consideration, the most effective group of fission product elements, as military agents, are those whose half-lives range from several weeks to the order of a year. This group of fission products will serve as the basis for the values subsequently given. More precisely, it will be for a mixture of fission products that exist in an irradiated natural mixture of uranium for a period of 100 days which is then allowed to cool for a period of 60 days before removal of the fission products as a group.

As a result of tracer studies done at Berkeley, and subsequent experiments including an investigation of radiation effects which were accomplished elsewhere on the Project, the following cursory picture has been compiled. The inhalation of 10 millicuries of the unseparated fission product mixture described above is estimated to be a minimum lethal dose for the average adult human. It is presumed that lethal injury will arise in the main through pulmonary damage rather than bone marrow destruction. The oral ingestion of at least 100 millicuries of such a mixture would be required to produce lethal injury which in this case would arise primarily from bone marrow damage produced from the strontium and barium absorbed from the digestive tract and subsequently deposited in the skeleton. An estimate of the amount of this fission product mixture required to produce external gamma ray injury can best be expressed in the following manner; 1 curie of radium gamma ray equivalent per square meter spread over a large plain area will produce at a level of 1 centimeter from the ground - 0.8 roentgens per minute, 10 centimeters from the ground - 0.6 roentgens per minute, and 100 centimeters from the ground - 0.4 roentgens per minute. Expressed in terms of roentgens per day, corresponding values are 115 roentgens, 86 roentgens, and 57 roentgens, respectively. In estimating these values, an average gamma ray energy of 0.7 Mev was assumed and absorption in the air as well as self absorption in the soil have been ignored. The corresponding amount of beta irradiation is very difficult to estimate in view of the variation produced by the different thickness of articles of clothing, et cetera. In general, however, it is likely that the gamma ray effects will predominate as the more destructive. Inasmuch as 100 r of total body radiation can be expected to produce, in a significant number of individuals, some degree of irreversible radiation damage, it would appear that a flux of gamma rays at this intensity would render such an area essentially uninhabitable. It should be kept in mind that the values given above for gamma radiation represent a hypothetical situation inasmuch as distribution will never be uniform and there will be other variations due to the presence of buildings, trees, and irregularities of terrain. A detailed discussion of the amounts of material required to produce crop damage is presented in the accompanying report. A more precise evaluation of the quantities involved for the sterilization of agricultural lands must await the accumulation of further scientific knowledge in this field of investigation.

In addition to the critical effect upon living plants following the contamination of large areas, there is a further consideration which

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presents a most ominous complication. Assuming a relatively uniform and widespread deposition of fission products over areas of many square miles, there will arise varying and unpredictable concentrations of this activity as a result of rain or melting snows. It must be realized that initially a large fraction of the deposited fission products will be on the surface of the soil, plants, buildings, roads, et cetera, as a thin film of dust. Rain or melting snows will wash a significant fraction of these materials away and they will be accumulated in the run-off water and may be carried considerable distances to another location. It is quite logical that a redistribution in a concentrated form would prove most disturbing, particularly from the point of view of gamma radiation if such removal and redistribution should occur in a thickly populated area.

The possible methods of distribution of fission products that are of military significance have been investigated only to a very limited degree and on an extremely small scale. Such methods were developed primarily at Berkeley for the purposes of studying the behavior of fission product aerosols following their inhalation by animals. Stable aerosols may be produced by depositing fission products upon a smoke producing agent, as for example, the zinc hexachlorethane-ammonium perchlorate mixture which has been used for many years for the purpose of obscuration. Such a type of preparation would appear well adapted for producing fission product aerosols to subject urban populations to fission product poisoning by inhalation. Other possibilities present themselves such as dispersal of a fine powder by means of a bursting charge, the reduction of the principal fission products to a metallic state and their subsequent combustion to form finely divided oxide smokes, the production of fine sprays of solutions of fission products, and the dispersion of a fission product mixture in the form of small particles of the size of the order of 0.1 millimeter in diameter. These are problems about which there are many individuals better qualified than I to present intelligent suggestions. It should be pointed out that in many instances, it is to be presumed that where aerosol concentrations of fission products can be created at sufficient levels to produce serious biological damage as a result of inhalation, there will occur the deposition of such suspensions upon the ground in sufficient quantities that will approach, if not exceed the radiation flux, that will result in severe external gamma ray damage to individuals so exposed.

There are known at present very few and relatively inadequate measures that can be employed to combat the problems arising from radioactive warfare. In the first place, the removal of long-lived fission products, once they have become either deposited within the lungs or absorbed in the body, has been unsuccessful. Absorption from the digestive tract following oral ingestion can be reduced significantly by increasing the calcium content of diet for several weeks before administration of the fission products. The administration of calcium or strontium at the time of absorption or subsequently, is not of significant value. The administration of strong cathartics at the time of oral ingestion would be of value to reduce the

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time interval when the unabsorbed fission products would remain within the digestive tract and hence reduce the degree of local radiation of these organs. However, absorption of fission products from the digestive tract is not significantly reduced by the use of cathartics. Obviously, it is not practical to adequately protect individuals from external gamma radiation if they are to move about in areas which have been heavily contaminated. The type of lead armour that would be required would weigh many tons. In addition, it should be pointed out that there is no satisfactory method for combating the effects of radiation once the individual has been so exposed. In brief, there is no satisfactory method of reducing the effects on personnel from fission products either following introduction of these agents into the body or after damaging external body exposure has been received.

The recent and illuminating experiences from Operation Crossroads emphasizes the difficulties that will be encountered when external objects become contaminated with fission products. It is essentially impossible to leach them from soils and the difficulties that will present themselves for the decontamination of buildings, roads, and other man-made structures may be expected to be almost equally insurmountable. In other words, once these agents are deposited, the treatment of both animate and inanimate objects that have become infected with radioactivity would appear to be an almost hopeless task in light of our present knowledge. The previous preparation of areas that may be expected to be so exposed offers only limited encouragement.

The most significant remedial measures that may be taken following the deposition of fission products will fall into two major categories. First, the rapid evacuation of personnel in such areas as may be infected, and a prompt survey of all such individuals so that those who have received sufficient material to expect serious damage may be hospitalized for whatever palliative measures may be available to reduce their distress. At the same time, such a weeding out process makes it possible to release individuals who are relatively free from radioactive contamination for whatever activities that may be needed under such circumstances. It is possible to organize a very rapid and relatively precise means for making the type of discrimination noted above if proper arrangements have been made beforehand. The second phase of this problem is, of course, the prompt monitoring of infected areas so that the degree of contamination and danger can be properly determined. The detection of damage to individuals from external gamma ray irradiation is less satisfactory. This is due to the fact that frequently the amount of irradiation required to produce immediate reactions of radiation sickness such as nausea, vomiting, et cetera, is not far from the lethal dose. The change in number and distribution of the leukocytes of the circulating blood is relatively sensitive to amounts of radiation in the range of 50 to 200 roentgens. However, due to the fact that the procedure of taking a blood count requires of the order of thirty minutes, it might be difficult to adequately examine large numbers of individuals within a short space of time.

The possible types of application of radioactive agents as military weapons can be initially divided into two major classifications;

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strategic and tactical. One of the principal strategic uses of fission products will probably be against the civilian population of large cities. It can be well imagined the degree of consternation, as well as fear and apprehension, that such an agent would produce upon a large urban population after its initial use. Apart from the effect upon the morale of the populace, there is of course, the possibility of rendering large areas within the city uninhabitable due to the prolonged gamma radiation of such contaminated areas. While it is entirely likely that the source of fear induced by such a weapon would be diminished as the population became better informed as to the nature and degree of hazard to be expected, the fact that large sections of cities would be rendered untenable would seriously dislocate the normal functioning of the nation as a whole were many cities to be involved simultaneously. Contamination of resevoirs does not appear to be a very effective use of fission products due to the fact that the majority of them would very quickly attach themselves to the concrete or earth containing the water and those that did not remain behind would tend to be caught in the water system with the result that little if any active material would actually reach the individuals dependent upon the water supply. It is possible, of course, that contamination of a very small resevoir by a large amount of active material might conceivably produce some effective contamination of the water, but even here, I do not believe it likely that the effectiveness of such a procedure would warrant the use of the large amount of material required. It would appear that fission products might be very effective for the denial of access to small key areas, notably railroads, shipyards, docks, highly concentrated large industrial establishments, as for example steel mills, power plants, factories producing essential commodities, et cetera. The advantage, of course, of this type of interruption of function is that the regions so treated are not physically destroyed and if the appropriate fission product mixture is employed, the interval during which such areas are rendered inaccessible can be pretty much selected at will.

Possible tactical applications that are fairly obvious are the denial of certain areas to troops, notably beach heads, narrow mountain passes, canals, et cetera. The direct use of fission products either against massed troops or against personnel in trench fortifications, not readily neutralized by more conventional agents, might be quite effective. The possibility also presents itself of the contamination of military materiel of various types, as for example, aircraft, quartermaster stores, ammunition dumps, et cetera. It is entirely possible that the use of fission products might be effectively extended against naval vessels either by shelling, using missiles containing fission products, or by spraying the material over the entire ship.

It is extremely difficult for me to make intelligent evaluations of the relative importance of different strategic and tactical uses of radioactive agents since I am quite unfamiliar with military science. Before leaving this phase of the application of radioactivity to warfare, it is pertinent to point out that the amount of fission products produced in creation of sufficient plutonium for a bomb would be adequate to render uninhabitable for a period of weeks to months an area that is comparable to that destroyed by the explosion of a single bomb. When it is considered that is is possible that within the next decade there will be produced plutonium in amounts which may approach an annual level in the range of tens of tons, it becomes apparent a nation producing such material at this level would possess the potentiality of rendering tens of thousands of square miles completely uninhabitable even for intervals of the order of a few days.

I strongly feel that the best protection that this nation can secure against the possibilities of radioactive agents being employed as a military tool by some foreign power is a thorough evaluation and understanding of the full potentiality of such an agent. Even if it were possible to predict the evil consequences that will result from the use of such an unpleasant military implement, such conclusions that could be made would be inadequate. In other words, I believe that it is necessary for the adequate defenses of this nation that an active and comprehensive examination of the entire problem be made by the armed services. Such a program, I feel should be carried out by the Chemical Warfare Service with the collaboration of other interested branches of the army and the navy. Inasmuch as it is apparent that such studies must be made by means of large scale experimentation, as well as laboratory research, it will be essential that there be made available in some isolated region an extensive proving ground. Here a large variety of field trials could be conducted, the nature of which are suggested in earlier discussions in this report.

To me, it would appear that the Chemical Warfare Service, in view of its long-standing experience in the use of other chemical and physical agents of warfare, would be best adapted to undertake and supervise such a program. In addition, it would appear highly desirable to appoint a civilian advisory committee composed of a group of chemists, physicists, and men trained in the medical and biological sciences. This group of civilian scientists, which would presumably be drawn from qualified individuals who have had extensive experience in the different aspects of the recent developments in nuclear energy, would serve to assist and advise the armed forces whenever such help would be needed. I believe that it would be inappropriate as well as difficult to seek the assistance of universities for direct research aid on most of the problems of investigation that the program indicated above would require. However, the fundamental knowledge in the fields of chemistry, physics, and medicine that is in the hands of the civilian scientists should be drawn upon freely.

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