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EVALUATION OF PERSONNEL EXPOSURE FROM STRATOSPHERIC FISSION FRAGMENT CONTAMINATION ON AIRCRAFT

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INTRODUCTION

The publicity given to nuclear detonations and the associated radioactive fallout has made the general public conscious of nuclear radiation. As a consequence, numerous investigations have been initiated in the field of radioactive contamination. One such study that has received considerable attention is the world wide Strontium-90 buildup and the potential health hazard to personnel. Another area that has attracted attention, but not quite the publicity, has been the accumulation of very fine particulate fission product debris in the stratosphere. It is this source of contamination that contributes to the buildup of radioactive debris on jet aircraft that routinely fly above the tropopause.

The Air Force first became aware of this problem in conjunction with a monitoring program established to determine the radiation exposure to personnel working on aircraft that were contaminated during the course of penetrating newly formed nuclear clouds. The subject aircraft were a part of a great number that were undergoing a major modification program. Although the radiation monitoring program was originated because of the presence of contamination on aircraft that had been flown through nuclear clouds in the course of a specific mission, the monitoring procedures were practiced on all aircraft involved in the modification program. Thus it was discovered that contamination on aircraft that had not penetrated nuclear clouds existed.

In view of the existence of this stratospheric reservoir of contamination, and the frequency with which Air Force aircraft operate at these altitudes, it was deemed advisable to conduct an extensive study to determine the extent of the contamination problem, the characteristics of the contamination, and to

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interpret the radiation levels observed in terms of an exposure problem to personnel.

Permissible Levels of Contamination. As of this date there is no specific guidance published in the form of a National Bureau Handbook that is directly applicable to interpreting the significance of radiation exposure to personnel from residual fission product debris found on materiel. However, there are recommended limits and general procedures to be followed that are outlined by the National Committee on Radiation Protection(NCRP). They are presented in publications such as: National Bureau of Standards Handbook (NBS) #52, "Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water"; NBS #59, "Permissible Dose from External Sources of Ionizing Radiation"; and an addendum to NBS Handbook #59, "Maximum Permissible Radiation Exposure to Man".

Using these recognized documents as a basis of departure, guide lines were constructed for acceptable levels of external radiation (1), and permissible air and water concentration (2). Figures 1 and 2 define limits for external exposure as a function of the age of the debris for the uncontrolled and controlled* areas. In calculating the data for

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*Controlled Area - A defined area in which the occupational exposure of personnel to radiation or to radioactive material is under the supervision of an individual in charge of radiation protection. All other areas shall be considered as uncontrolled as far as radiation exposure is concerned.

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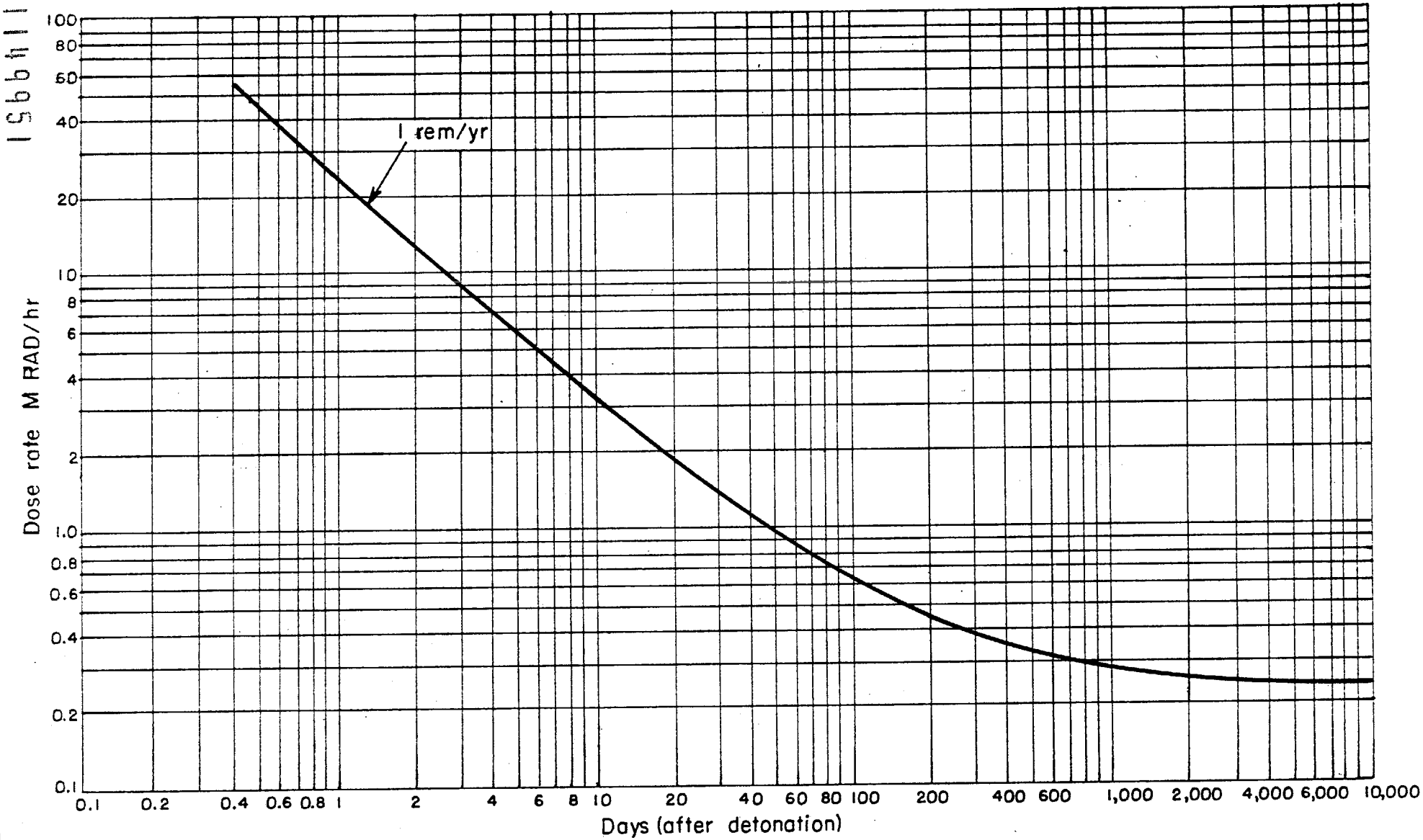

Figure 1 Maximum permissible levels for whole body skin dose versus age of fission product debris. (168 hour week uncontrolled)

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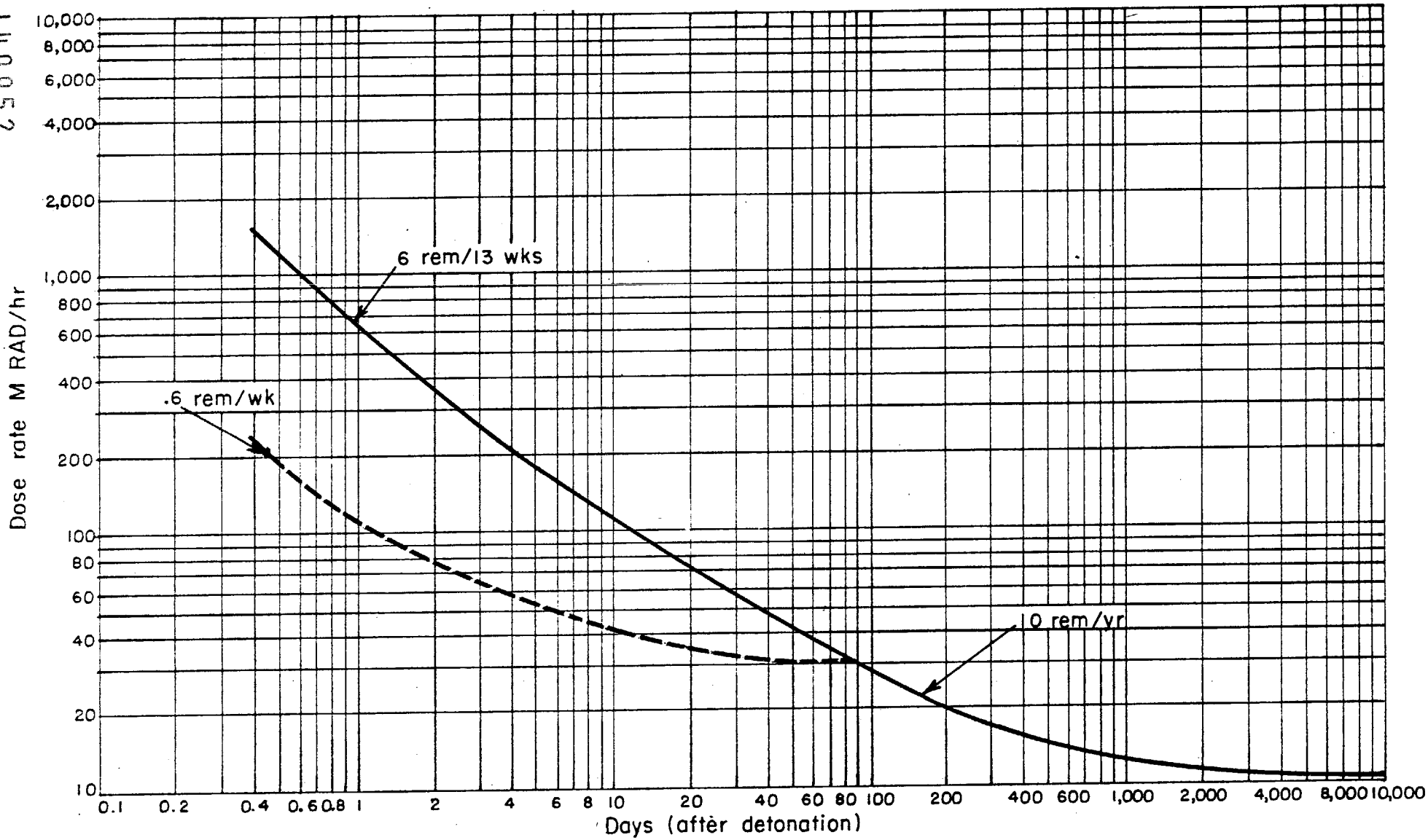

Figure 2 Maximum permissible levels for whole body skin dose versus age of fission product debris. (40 hour week controlled)

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the curves the following criteria are considered: the age of the fission product debris and its rate of decay; the exposure to the whole body skin as the Maximum Permissible Dose (MPD) as defined by the NCRP; and the beta-gamma survey to be conducted at 1 inch from the surface of the contaminated item using a Geiger-Mueller type survey instrument.

It will be observed that the limits as shown on Figures 1 and 2 vary with the age of the contaminant rather than being expressed as fixed values. This procedure is necessary since the debris is a composite of a number of isotopes of varying half-lives. When the debris is young, it is decaying very rapidly and the integrated dose delivered over a given period is considerably less than for older debris of comparable intensity.

There are a number of methods for estimating the age of the contamination. One of the simplest and most expedient methods of determining the age of the contaminant is to assume that all the activity is associated with the debris from the most recent nuclear test series wherever it may have been carried out. The United States Atomic Energy Commission Health and Safety Laboratory employs this method in their radioactive fallout studies [3]. A more precise method of estimating the age of the contamination is based on the theoretical decay rate of $t^{-1.2}$. Figure 3 is a graph of the relationship of the time interval (Δt) between two successive activity measurements and the age of the fission products at the time of the initial measurements (t_1) [1]. The parameter "f" is obtained by dividing the activity reading taken at the end of the time interval (t_2) by the activity taken at the beginning of the time interval (t_1). From

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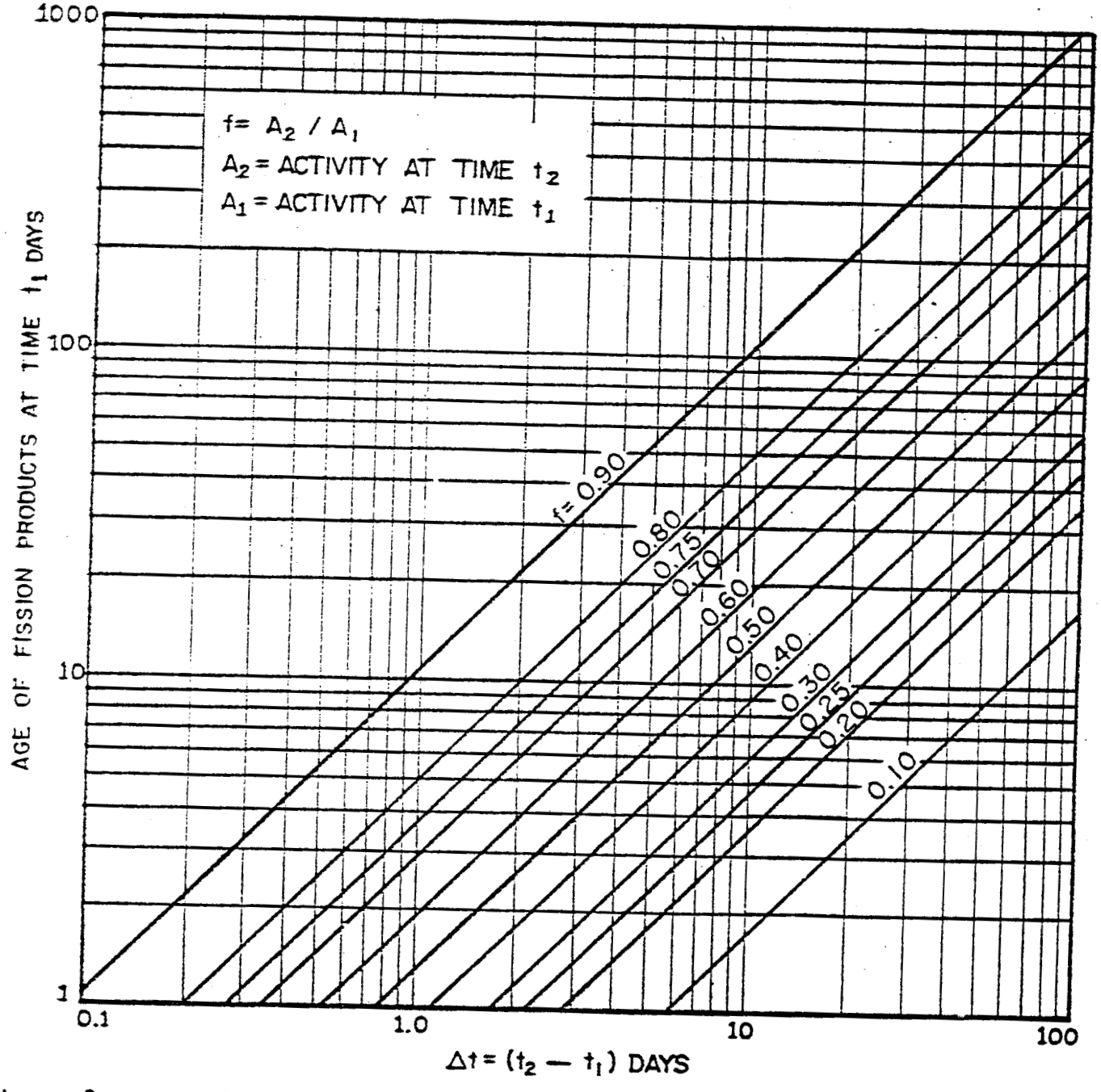

Figure 3 Age of fission products vs time interval of measurements.

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the graph, using the parameters t and f, the age of the fission products is determined for the time the initial measurement was taken. Other means of fission product age determination consist of somewhat involved chemical, gamma spectrographic, or mass spectrographic analysis.

The exposure limits recommended by the NCRP fall into several categories. There are those limits set up for the occupationally exposed, a somewhat select group in that individuals presumably of the greatest susceptibility (i. e., infants and children) are not included. These personnel are in general under some form of radiation control and frequently work in an area that is considered controlled. The Maximum Permissible Dose (MPD) in rem to the skin of the whole body of these personnel is equal to 10 times the number of years beyond the age 18, provided no annual increment exceeds 30 rem. The average MPD is expressed by the following formula:

$$MPD = 10\ (N-18)\ \text{rem}$$

where N is the age in years of the exposed personnel and is greater than 18. One other stipulation is that the dose to the skin in any 13 weeks shall not exceed 6 rem.

Figure 1 is so construed that if the dose rates measured on a given item do not exceed the levels for a given age of fission product contamination (e. g., 100 mrad/hr for 10 day old debris), a worker may work on the item for 40 hours per week without exceeding his Maximum Permissible Dose (whole body) for controlled areas of either 6 rem/13 week or 10 rem/year.

For individuals that are not under radiation control, the recommendation of the NCRP are that the levels should be readjusted downward. With this

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downward adjustment, the risk to the individual is negligible so that small transient deviations from the prescribed levels are unimportant. This downward adjustment for individuals outside the controlled area shall be such that it is improbable that any individual will receive a dose of more than 1/10 that prescribed by the limits set for the controlled areas. Figure 2 sets forth limits for uncontrolled areas. Using these guide lines, personnel may be in the presence of the contaminated material continuously, 24 hours per day, 7 days per week, and not receive more than 1 rem whole body dose to the skin in one year. This compares to an average natural background radiation of .15 roentgen per year.

As previously mentioned the monitoring techniques to be followed require that the survey be made with a G-M type survey instrument and measuring the beta-gamma radiation at approximately one inch from the surface of the item suspected of being contaminated. This procedure will insure that neither the skin nor the whole body will receive excessive exposure. Furthermore, there will be no significant increase in the general radiation level if a number of contaminated items are stored together.

In addition to the external radiation exposure problem, there is also the possibility of internal exposure via the uptake of fission product debris either by inhalation or ingestion.

The control of the internal dose is achieved by limiting the body burden of the mixture of the radioisotopes found in the contaminant. This is again a function of the age of the debris. The guide lines are such that they are consistent with those suggested for external exposure levels.

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Figures 4 and 5 give the permissible limits for contaminated air and water in terms of disintegrations per minute per cubic meter (dpm/m^3) of air and dpm/m^3 of water as a function of the age of the fission product debris. These guide lines are applicable to the uncontrolled situations and as such it is improbable that any individual would receive more than 1/10 the permissible level of that established for the controlled area. As in the case of the guide lines for the external radiation problem, the guide lines in Figures 4 and 5 reflect the varying isotopic composition of the contaminant with age, the critical body organ, and the maximum permissible average concentrations of the individual radionuclides in air and water as given in the forthcoming revision of NBS Handbook #52 (4).

A total of 70 radioactive isotopes were considered in the construction of these curves. This accounts for 95% of the isotopes present when the age of the contaminant is 1 day old and more than 98% of the isotopes when the contaminant is 2.13 days old or more. Twelve possible critical organs were considered in the determination of the Maximum Permissible Activity. Since the MPA for the lung and the gastrointestinal tract is affected by the chemical form of the radioactive material, MPAs were calculated for each of these organs for both soluble and insoluble chemical forms. Although the contaminant is comprised of both soluble and insoluble material, the lower MPA for the completely insoluble contaminant was used in the construction of the curves where the lung and gastrointestinal tract are the critical organs. The gastrointestinal tract is the critical organ for fission debris of an age less than 2.8 days, thyroid to 3.5 days, lungs to 38.5 days and bone from 38.5 days on.

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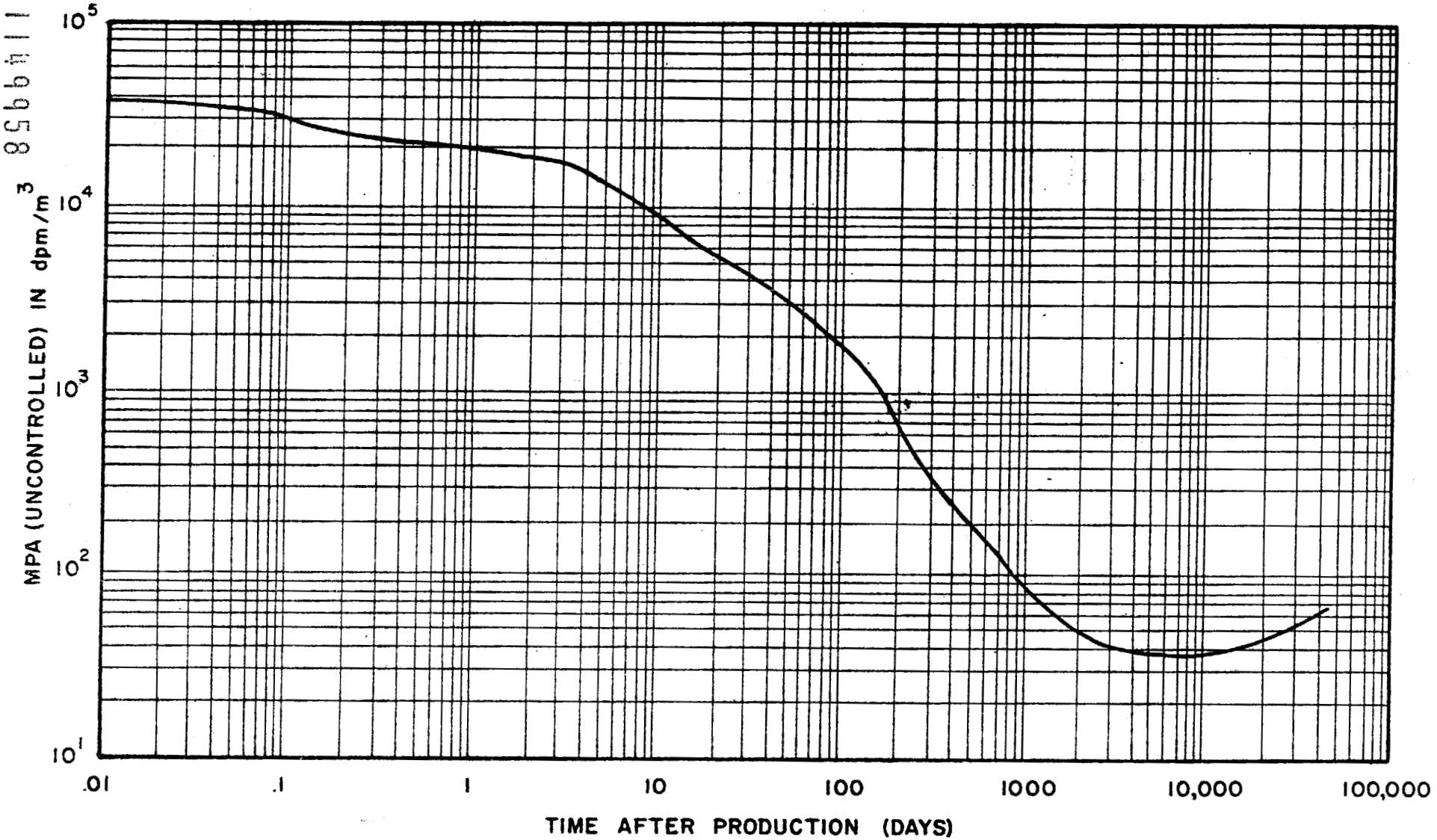

FIG. 4 MPA (UNCONTROLLED) FOR FISSION PRODUCT DEBRIS IN AIR VS. AGE OF THE FISSION PRODUCTS

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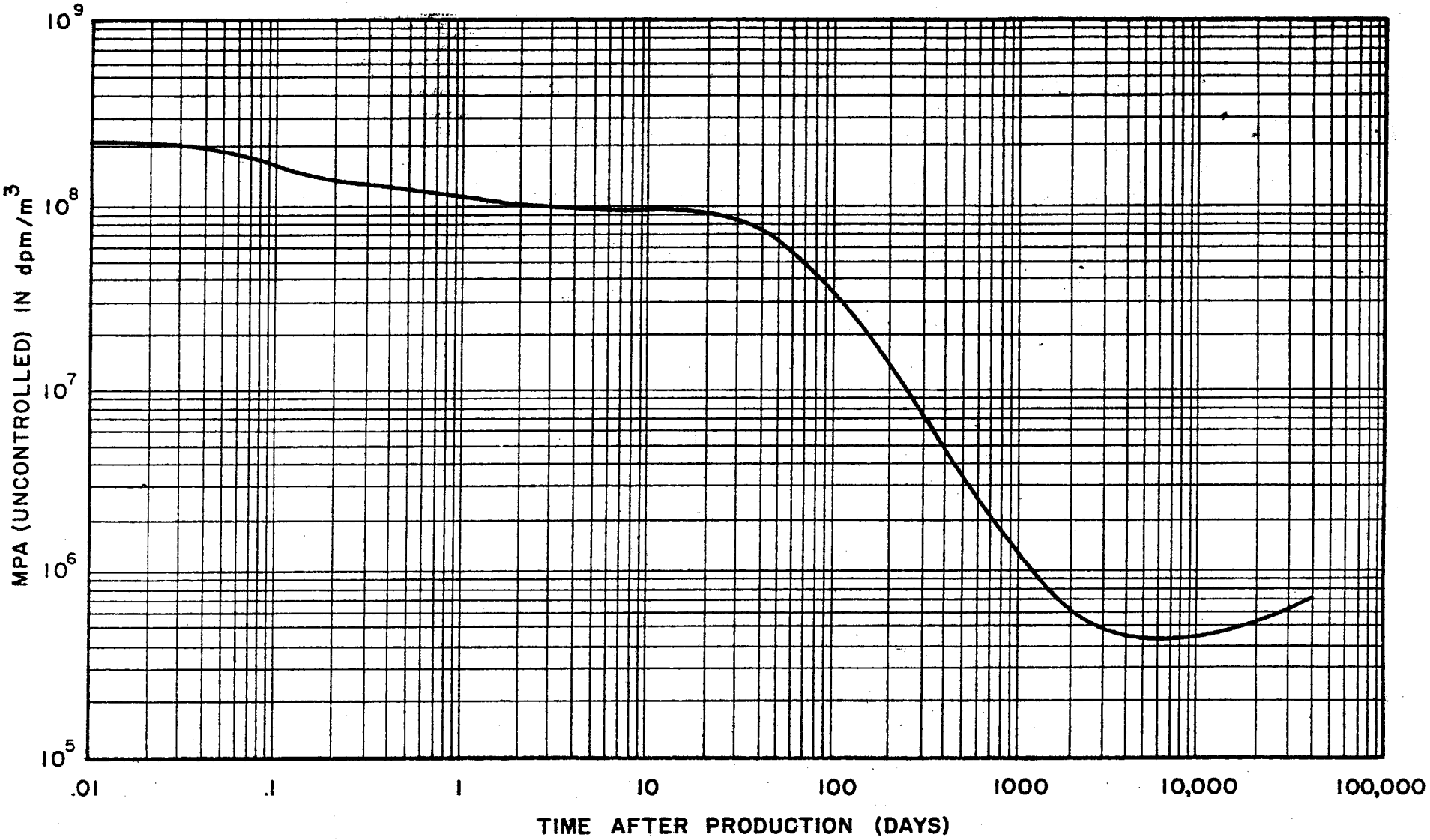

FIG. 5 MPA (UNCONTROLLED) FOR FISSION PRODUCT DEBRIS IN WATER VS. AGE OF THE FISSION PRODUCTS

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The evaluation of the magnitude of airborne contamination under a given set of circumstances is relatively simple. This can be accomplished by taking air samples in the immediate vicinity of the breathing zone of the individual concerned, counting the sample and comparing the results with the guidance given in Figure 4.

In situations where air sampling is not feasible because of lack of equipment or other reasons, procedures have been employed to make a rough approximation of the potential airborne concentration by making a measure of the removable contamination using the swipe sampling technique. Correlation of this method with the air sampling technique has not been too satisfactory. The guide lines to be employed in this method are shown in Figure 6, dpm/150 cm^2 vs the Age of the Fission Product Debris. The same criteria as used in arriving at the values for permissible air and water concentrations and a resuspension factor approximately of 10^{-6} are followed in establishing this curve.

The interpretation of measurements made in an attempt to evaluate the magnitude of the potential ingestion hazard from fission product debris is not so readily accomplished. One rather simple and straight forward situation is that wherein contaminated water is of concern. In this situation, monitoring of representative samples of water at the point of release into uncontrolled areas is the most desirable. Guidance for this problem is given in Figure 5, however, there is a more common situation in which ingestion of fission product debris is likely to occur. That is in the course of transferring the removable contamination from the surface of the item of concern to the hand, then to the mouth

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through smoking or eating, and finally into the body via the gastro-intestinal tract. Figure 6 may be used in evaluating this potential route of internal exposure also.

Relative Contribution of External and Internal Radiation Exposure from Fission Product Debris on Aircraft. An extensive research program which extended over a two year period was initiated during the Atomic Test Series of 1956, Operation Redwing and continued through the Nevada Test Series of 1957, Operation Plumbbob [5]. The primary purpose of this research program was to determine the relative and absolute hazards associated with service work on aircraft that had been contaminated with radioactive fission product nuclides. At the time the project was initiated, there were large areas of uncertainty in the relative contributions of ingestion, inhalation and external radiation for workers on a contaminated aircraft. The basic studies were:

(1) Complete aircraft and engine survey for relative and absolute activities of alpha, beta and gamma radiation.

(2) Air sampling which related the concentration of the radionuclides in the air to beta-gamma fields and levels of removable surface contamination.

(3) Swipe sampling which related the concentration of removable activity to the beta-gamma fields.

(4) The determination of the contribution to the total dose of radiation exposure from the external field, the airborne contamination, and the removable contamination to personnel working on the contaminated aircraft.

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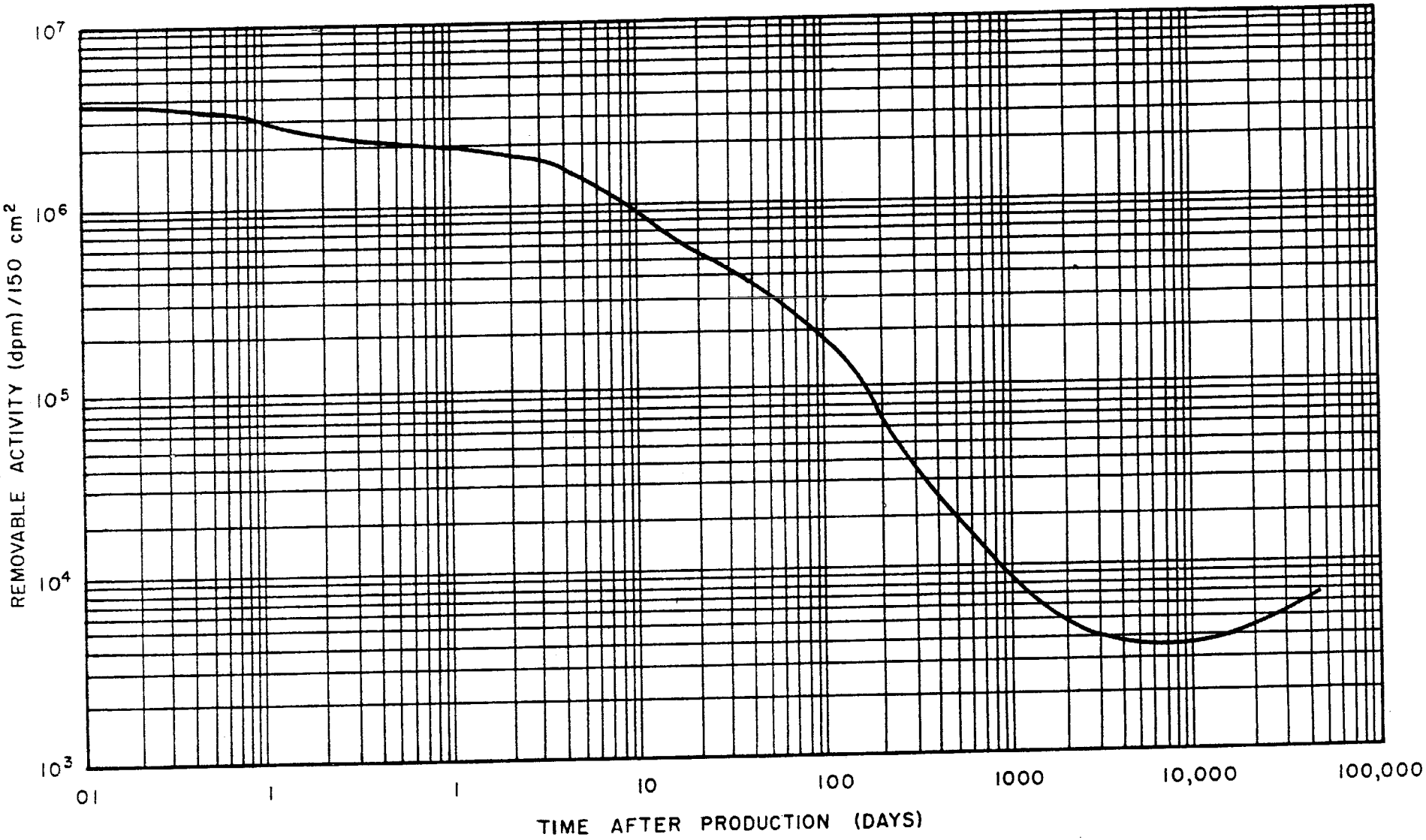

REMOVABLE ACTIVITY/150 cm² FOR FISSION PRODUCT DEBRIS ON CONTAMINATED SURFACES VS. AGE OF THE FISSION PRODUCTS

Figure 6

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To evaluate any of the radiological hazards with reference to aircraft maintenance men, it is necessary to know in some detail the variation of the radiation intensity at various positions on and in the aircraft and its engines. Thus extensive beta-gamma and gamma surveys were carried out on aircraft that had penetrated newly formed nuclear clouds. Autoradiographs of the contaminated aircraft show the fission product debris and associated carrier to be finely divided and rather uniformly distributed over a given smoothe area. Maximum concentrations are noted on areas of impaction such as the leading edge of the wing or on rough surfaces where screws, latches, or insets or crevices exist. These variations are illustrated in Figures 7 and 8. Table I is derived from the data collected from the external radiation measurement program and gives the normal distribution of radioactivity on the surface of an aircraft that has flown through an atomic cloud.

The gamma data are not particularly useful for comparison of relative surface contamination in different parts but do indicate the general level of radiation which will be received by a workman in that area. The beta measurements are more useful for the surface survey and illustrate a wide variation in the contamination levels over the aircraft. The maximum range of activities appear to be about a factor of 1000 from the exhaust cone and turbine blades of the engine to the cockpit and other sealed compartments. Sufficient data now exists to be able to state that, in general, the levels of contamination ranged from 1000 units for the turbine blade section; 100 for areas of impingement such as the leading edge of the wing, nose, etc; 10 for the sides of the fuselage; to 1 for the cockpit and other sealed compartments. On the basis of these data, it is possible to

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TABLE I

Normal Variation of Radiation Level on Contaminated Aircraft
(Relative values in mr/hr)

Position	Surface Contamination beta at 1"	Gamma Field at 1"
Nose	150	15
Leading edge of wing outboard	100	20
Leading edge of wing inboard	150	35
Nose of tip tank	100	10
Side fuselage near wing	40	35
Cockpit	1	10
Fuselage	5	5
Leading edge horizontal stabilizer	40	8
Wheel and Wheel Well	1	35
Starter hub	200	30
Top of wing outboard	10	10
Top of wing over engine	100	30
Just inside tailpipe	300	30
Bomb bay lip	100	30
<u>After engine demounted</u>		
engine well in wing	20	20
exhaust stack in wing	1000	100
exhaust cone engine	1000	100
rotor and stator blades engine	1000	100
exterior engine surface	50	100

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FIGURE 7. DISTRIBUTION OF FISSION FRAGMENT DEBRIS ON LATCHES AND SCREW HEADS

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FIGURE 8. DISTRIBUTION OF FISSION FRAGMENT DEBRIS ON LEADING EDGE OF WING

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estimate with reasonable accuracy the entire contamination problem of an aircraft by a survey of a representative area. The leading edge of the wing is suggested as it is readily accessible and presents the opportunity for a number of measurements to establish a reliable measurement.

In order to compare the potential internal exposure levels with the external radiation field both inhalation and ingestion studies were performed. Air samples were taken in the immediate vicinity of the aircraft and downwind from a group of highly contaminated aircraft during the period of the beta-gamma surveys. Sampling was also carried out in the breathing zones of the personnel during routine inspections and overhaul of the aircraft which included the removal of the engines. Millipore filters and pumps were used for these measurements.

An extensive study was made of the contribution of the removable activity to the airborne exposure problem as well as the uptake of the contaminant via transfer from the aircraft to hands of the mechanic and then to cigarettes or bread that he might handle with his contaminated hands. As might be expected from what was stated earlier, the ratio of the air activity to the swipe varied tremendously. This is due for the most part to the fact that the air samples represent the concentration of the contaminant in the general vicinity of the sampling, whereas the swipe levels apply to a very limited area. However, the ratio of the airborne contamination to surface contamination is approximately 5×10^{-5} which is in general agreement with other research efforts in this area [6,7].

In evaluating the ingestion problem resulting from the transfer of removable surface contamination from the aircraft to the man via hands,

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bread, and/or cigarettes, personnel rubbed their hands vigorously on the contaminated surfaces then handled bread or cigarettes. In general, the maximum level that could be transferred from the aircraft to the hands were on the order of 30% to 40% of that measured on the aircraft surface. Of this, only 15% to 20% was transferred to the bread and at most 5% to the cigarettes. It should be emphasized that in this instance every possible effort was made to maximize the extent of transfer of the contaminant. For example, the hand was vigorously rubbed on the freshly contaminated surface and the cigarettes individually rolled between the hands. Ordinary transfer would not be expected to give more than 1/10 of this amount.

In order to obtain a direct empirical measure of the radiation dose to aircraft maintenance personnel who performed various operations on the contaminated aircraft, film badge dosimetry, pocket dosimetry, and biological sampling were employed. This made it possible to compare the film badge readings with the doses estimated from the measured gamma fields around the aircraft. It also permitted a comparison of the actual quantity of radioisotopes inhaled and/or ingested and that predicted by air sampling and the transfer experiments.

Using these experimental data, it was then possible to assess the relative importance of the external, and the inhalation and ingestion hazard as well as the total dosage to personnel working in a given radiation environment. A portion of this data is summarized in Table II.

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TABLE II

Comparison of Air Concentration with Gamma Field

Location	Field mr/hr	Air Level Total Beta dpm/m^3	$\frac{\%MP_\gamma}{\%\ MPA\ (air)}$
RAMP In Nacelle	2500	935,000	1.9×10^3
Ramp Bkgrd	25	7,300	2.5×10^3
Inside Cockpit	320	45,000	4.2×10^3
2.5' from left Nacelle	400	39,000	6.5×10^3
Deep in airscoop	800	110,000	2.8×10^3
2' from wing root	170	5,800	5×10^3
Base of Engine	100	4,000	1.6×10^3
Background	17	2,400	4.4×10^2
Horizontal stabilizer	20	600	2.5×10^3
Engine Intake	70	1,300	3×10^3
Exhaust cone	130	9,700	9×10^2
Compressor section	80	22,000	2.4×10^2
Air Cond. well	90	500	1.2×10^4
Engine during reinstallation	60	800	1.1×10^3

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The conclusion that can be drawn from Table II is that whether on the ramp or in the hangar, the potential external radiation hazard will be on the order of a factor of 100 or more greater than the inhalation hazard. Practically, therefore, in the case of aircraft contaminated in flight by mixed fission products, the inhalation hazard may be disregarded.

A similar summary is included in Table III to illustrate the relation between the ingestion problem and the external gamma field.

A study of these data reveals that the external radiation hazard is at least a factor of 100, and on occasion approximately 1000 times more significant than the potential ingestion hazard. These data were compiled on the basis of crew members with freshly contaminated hands handling bread prior to eating it. Had the transfer figures been determined in the case of handling cigarettes, the contribution via ingestion would have been reduced by at least another factor of ten.

The findings discussed above as to the relative contribution of the total dose from the external field to that contributed via inhalation or ingestion are in keeping with the results of other work of this type. For example the Rongelap Natives received approximately 175r external gamma radiation dose yet analyses of human excretion indicated that the internal body burden was below peacetime tolerance levels for all isotopes except I^{31} and Sr^{89}.[8] In spite of the relatively unsanitary way of life of those natives, the external radiation dose was the controlling factor by far.

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TABLE III

Comparison of Ingestion Hazard and Gamma Field

Location	Ave γ mr/hr	Total dpm beta ingested	$\frac{\% MP_\gamma}{\% MPA (Ing)}$
Nose Area	26	1.4×10^5	8.8×10^2
		5.6×10^5	2.1×10^2
Engine	50	2.1×10^5	2.8×10^2
		1.2×10^6	6.3×10
		1.3×10^5	5.7×10^2
Engine	10	4×10^4	6.7×10^2
	25	4.3×10^5	1.3×10^2
	25	3.4×10^5	1.6×10^2
	25	2.1×10^5	2.6×10^2

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The above work may be summarized by stating that the radiation exposure to maintenance personnel who must work on aircraft contaminated with mixed fission products can be adequately defined by a survey of the beta-gamma field in which they work and will be the dominant contributor to the total dose over inhalation and/or ingestion by a factor of 100 or more.

Aircraft Contamination from Residual Stratospheric Nuclear Weapon Debris. The previous section was directed toward the relative contributions of external and internal sources of radiation to the total dose. It is reemphasized that this work was carried out on relatively highly contaminated aircraft that would be encountered only during nuclear test operations or wartime conditions. However, the relative significance should be equally applicable to aircraft contaminated to a lesser degree in proportion to the actual levels found.

Currently a situation exists in which both the military and civilian jet aircraft tend to accumulate stratospheric fission product debris during extended flights above the tropopause.[9] In view of the existence of this stratospheric reservoir of contamination and the frequency and length of time Air Force aircraft operate at these altitudes, it was deemed advisable to conduct an extensive survey program to determine the magnitude of this more normal kind of contamination problem and evaluate the magnitude of the radiation exposure to refueling and maintenance personnel that routinely work on the aircraft.

In order to develop an understanding of the buildup of radioactive contamination in aircraft that operate above the tropopause and subsequent exposure to personnel, an appreciation of the location, magnitude,

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and characteristics of the fission products in the stratosphere is necessary.

Libby [10] has proposed that once weapon debris is injected above the tropopause as in a typical nuclear test, it mixes rapidly throughout the stratosphere and falls back uniformly into the troposphere with a half-time of about 7 years. Machta [11] has postulated that stratospheric mixing is slow and that stratospheric distribution of fission products is still non-uniform. Martell [11] has proposed a model for the distribution which allows for a difference between the behavior of debris from U. S. Pacific tests and the U. S. S. R. thermonuclear tests. Since much remains to be known about the distribution of weapon debris in the stratosphere, considerable research is currently being performed in the field of upper air sampling.

The height of the tropopause varies primarily with latitude and time of year. For example the average height of the tropopause is about 36,000 feet for the month of January at Buffalo, 43° north latitude and 56,000 feet in the Miami area, 25° north. Whereas in the summer months the average height north or south across the United States is approximately 50,000 feet.

Vertical sampling of the atmosphere indicates the concentration of residual debris above the tropopause is much higher than that below. As a consequence, the amount of contamination found on an aircraft can be directly related to its operational altitude and the average height of the tropopause in the vicinity of its base of operations. Propeller driven aircraft fly almost exclusively in the troposphere, whereas most jets spend considerable time above the tropopause in the stratosphere at altitudes

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of approximately 30,000 to 40,000 feet or more. Thus, it is not surprising that higher levels of contamination are found on jet aircraft than on propeller driven aircraft.

Realizing that the level of contamination on the aircraft would no doubt be directly related to the time it operated above the tropopause, Air Force bases were selected to illustrate the effect of variation in the height of tropopause in the winter season. The bases were Tyndall AFB, Florida, Youngstown AFB, Ohio, and Kinross AFB, Michigan. F-102 jet aircraft were monitored. The monitoring program consisted of a beta-gamma survey 1 inch from the surface of the aircraft, air sampling in the immediate vicinity of the aircraft during refueling and maintenance activities, and a measurement of removable activity. Personnel wore film badges and pocket dosimetry during the program. Table IV summarizes the finding of the beta-gamma survey.

It is illustrated clearly in Table IV that the maximum levels of contamination exist on aircraft that routinely operate in the northerly latitudes. The levels on the aircraft are on the order of 5% of the permissible limit for uncontrolled exposure and 35% of the permissible limit for uncontrolled exposure for the engines based on an age of 90 days for the fission product debris. It is of interest that the level of contamination reaches a state of equilibrium. That is, the levels of contamination on the aircraft were essentially independent of the number of hours an aircraft had flown. The readings were considerably higher at those positions where the air flow changed direction such as

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TABLE IV[9]

Average β/γ Readings on Aircraft and Engines at Kinross, Youngstown and Tyndall AFBs.				
Base	Average β/γ Reading in mrad/hr on A/C	% of Permissible Level Uncontrolled (age-90 days)	Average β/γ Reading in mrad/hr on Engines	% of Permissible Level Uncontrolled (age-90 days)
Kinross (46° N)	.048	6%	0.28	40%
Youngstown (41° N)	.038	5%	0.14	20%
Tyndall (30° N)	.013	2%	0.07	10%

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the air intakes to the engine, dive brakes, elevators, and wing roots. Repeated air sampling indicated that the airborne contamination was essentially background. Levels of removable contamination were insignificant. Also there was no indication of any external exposure on the film badges or pocket dosimeters worn by the personnel.

B-52s and KC-135 aircraft were montiored at Castle Air Force Base. The monitoring of these aircraft provided a means of determining the order of magnitude of the radioactivity present on large Air Force jet aircraft. The Boeing 707 is a passenger version of the KC-135. These data are therefore directly applicable to the problem of possible exposure to civilians,both air and ground crews. A summary of the survey is presented in Table V.

The highest β/γ reading on an external surface was 0.13 mrad/hr on a B-52 and 0.06 mrad/hr on a KC-135. The highest reading on a B-52 engine was .30 mrad/hr and on a KC-135 engine, 0.60 mrad/hr. The levels on the aircraft are approximately 5% of the maximum permissible limit for uncontrolled conditions based on an estimated age of 90 days for the fission debris. The engines surveyed had been in storage for some time. The age of the contaminant was approximately 220 days. As noted, the level of contamination was approximately 25% of the permissible limit for uncontrolled conditions.

A comparison between the levels of contamination on jet engine and reciprocating engine aircraft is shown in Table VI. It is noted that the contamination is on the order of a factor of 3 lower for the propeller driven aircraft and this difference would be even more pronounced

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TABLE V. (9)

Average β/γ Readings on Aircraft and Engines at Castle Air Force Base

Type of Aircraft	Average β/γ Reading in mrad/hr on A/C	% of Permissible Level Uncontrolled (age-90 days)	Average β/γ Reading in mrad/hr on Engines	% of Permissible Level, Uncontrolled (age-90 days)
B-52	.038	5%	.055	12%
KC-135	.022	3%	.152	33%

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TABLE VI.[9]

Average β/γ Readings on Aircraft at Kirtland AFB

Group of Aircraft	Average β/γ Readings in mrad/hr	% of Permissible Limit, Uncontrolled (Age-90 days)
Jet Aircraft	.021	4%
Reciprocating Engine A/C	.007	1%

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on aircraft operating from bases located at more northerly latitudes than Albuquerque, New Mexico. As in previous tables, the levels of contamination were only a fraction of the values given in Figure 2.

Swipe samples were made over an area of approximately 150 square centimeters with planchets covered with filter paper. It was found that the amount of activity obtained with a swipe is dependent on the pressure exerted on the swipe and the exact size of the area over which the swipe is made. Another important factor is the nature of the surface on which the swipe is made, the curvature, amount of grease or rust, etc. The largest number of disintegrations per minute (dpm) on a swipe from an aircraft was 14,729 which was found on a B-52 at Castle AFB. This is approximately 7 percent of the maximum permissible limit as determined from Figure 6. The largest number on an engine was 32,585, 15% of the maximum permissible limit, which was found on an F-102 engine at Kinross AFB. The reproducability of the procedure was determined to be ±30% for a majority of the samples checked.

A large number of air samples were taken on aircraft and engines. These were generally obtained while personnel were working in the immediate vicinity. In only four cases out of 75 was a detectable amount of activity observed. On the most active sample, 109 dpm/m^3 of air were found, approximately 6% of the permissible level.

The alpha contamination on aircraft was monitored with an Eberline PAC-1G alpha survey instrument. A large number of swipes and air samples were also made and then counted with a Nuclear-Chicago D-47 gas flow counting tube. In no case was detectable alpha contamination found.

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The results of a typical radiation survey of both jet and reciprocating engine aircraft are given in Table VII.

Comparisons were made of contamination inside the crew compartment and the external surfaces of the aircraft. Air intakes, leading edges of the wings and other areas of impaction showed levels on the order of 0.1 mrad/hr whereas the levels in the crew compartment were below detection. Removable contamination was also a factor of 100 or more below the removable material on the external surfaces. Essentially no airborne contamination was observed in the compartments.

Contamination Control and Decontamination. Although the levels of contamination on aircraft that fly above the tropopause are such that decontamination of personnel or aircraft is definitely not necessary at this time in terms of a radiation problem from either external or internal exposure, policy may dictate that some effort should be made to minimize the spread of even this small amount of contamination that is detected.

Common sense dictates that good hygienic measures should be encouraged as is the policy in any well-managed industrial operation. In this particular situation, the emphasis on cleanliness should be directed toward the individuals coming in contact with the exterior surfaces and engines of the aircraft; e. g., refueling and maintenance personnel. No appreciable exposure of any kind exists in the case of aircrews and passengers. Company management, Industrial Health Hygiene Personnel, and medical personnel should be advised of the existence of the situation and made aware of the minimal exposure problem. A problem of contamination

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TABLE VII (9)

Summary of Results of Aircraft Monitoring Program at Kirtland AFB, N Mex

	F-86s of 93rd Fighter-Interceptor Sqdn	Other Jets	Reciprocating Engine A/C
No. of A/C Monitored	35	106	35
No. of β/γ Readings	35	126	35
Average β/γ Readings in mrad/hr	.023	.021	.007
Maximum β/γ Readings in mrad/hr	.06	.20	.06
% of β/γ Readings Above .10 mrad/hr	0.0	3.1	0.0
Average β/γ Readings in mrad/hr (1 Mar-30 Apr)	.023	-	-
Average β/γ Readings in mrad/hr (27 Jan-5 Mar)	.025	.021	.005
No. of Swipes	35	126	157
Average Swipe Count (dpm)	93	157	196
Maximum Swipe Count (dpm)	455	5,305	2,029
No. of Air Samples	-	16	-
Average dpm/m^3 in Air	-	0	-

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of this magnitude can be readily handled by merely emphasizing washing of the hands and wearing of coveralls to employees engaged in refueling and maintenance. It is suggested that the personnel involved be provided with coveralls labeled with the name of the individual and airline. Furthermore, that they be encouraged to remove the uniform at the completion of the day's work and that it be stored in individual lockers provided by the company. In addition, the company should collect the coveralls weekly for laundering.

For the sake of completeness of this report, the following guidance is included for situations in which high levels of contamination might be encountered. These levels would be on the order of 10 to 100 times more than those presently experienced. It is not anticipated that such conditions would ever occur except as a result of the inadvertent penetration of a freshly formed nuclear cloud.

A change station can be provided for personnel that work on contaminated aircraft. Prior to the beginning of the work day, personnel may be provided with coveralls or a change of clothing, film badge, and pocket dosimetry. At the conclusion of the work period, these items and tools may be left in the portion of the change station designated as the contaminated areas. Figure 9 is a schematic of a personnel decontamination center. Thorough washing with soap and water is the best general method for removing any possible contamination off the hands and other parts of the body, regardless of the contamination, whether it is virus as in colds, bacterial, or the infinitesimal amount of radioactive contamination. If the contamination is localized, it is often more

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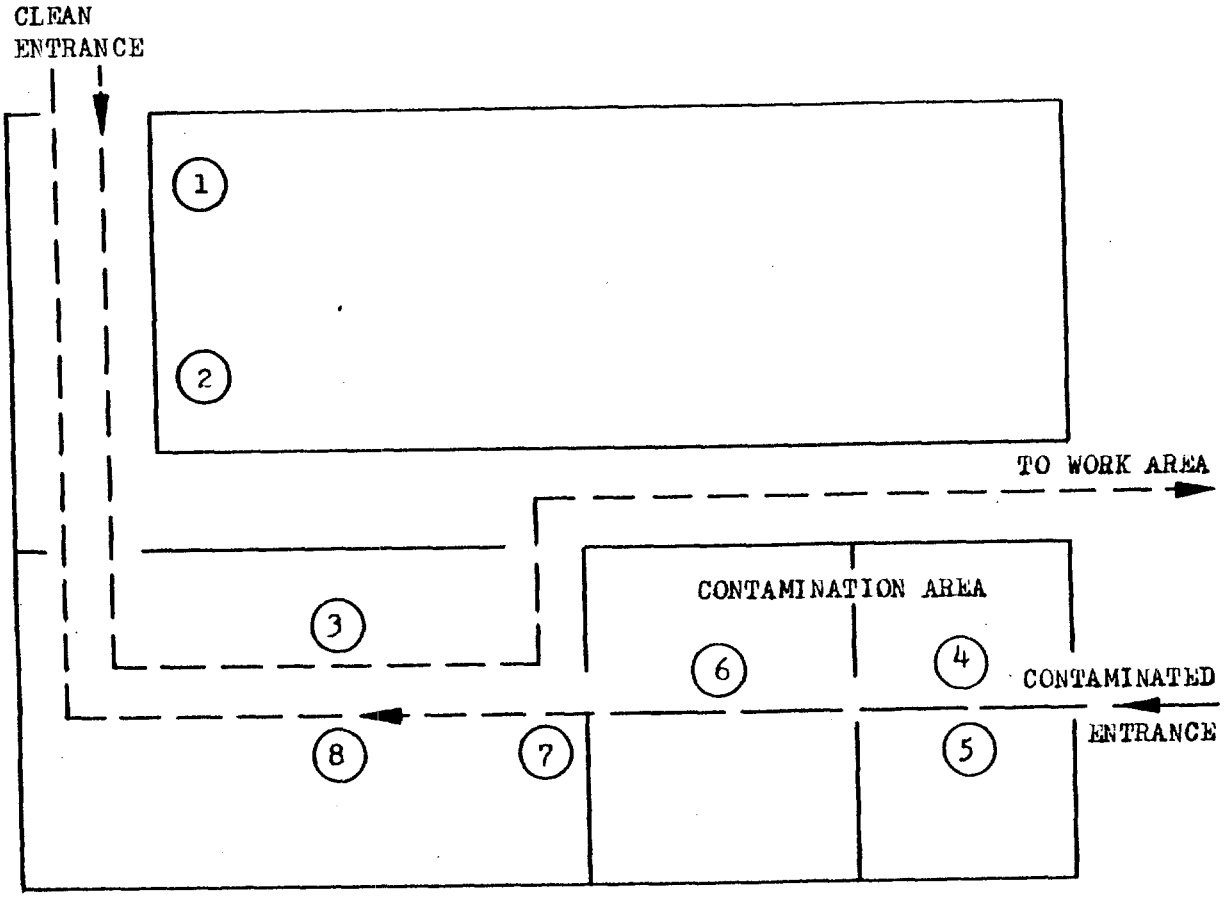
Figure 9



1. CLOTHING AND EQUIPMENT ISSUE
2. DOSIMETER ISSUE
3. CHANGE FROM PERSONAL CLOTHING TO WORK CLOTHING
4. REMOVE AND DEPOSIT CONTAMINATED WORK CLOTHING IN BINS
5. DEPOSIT DOSIMETERS
6. PERSONNEL DECONTAMINATION AREA, SINKS, SHOWERS, LAUNDRY FACILITIES
7. PERSONNEL MONITORING CHECK POINT, PORTAL MONITOR
8. DON PERSONAL CLOTHING

PERSONNEL DECONTAMINATION CENTER

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practical to mask off the affected area and cleanse with swabs, before risking the danger of spreading the contaminant by general washing. The recommended procedures [12] for general hand-washing are as follows:

a. Wash for not less than 2 minutes, nor more than 3 minutes by the clock with a mild pure soap in tepid water with a good lather, covering the entire affected area thoroughly. Give special attention to areas between the fingers and around the fingernails. The outer edges of the hands are readily contaminated and often neglected in the washing. Do no use highly alkaline soaps or abrasives. Rinse thoroughly and repeat, as monitoring indicates, until the desired degree of decontamination is achieved, but not to exceed three or four times.

b. If the above procedure is not sufficient to remove the contamination, acrub the hands with a soft brush using a heavy lather and tepid water. This scrubbing is primarily to agitate the cleansing agent, and hence prolonged scrubbing without change of reagent is of questionable value. For this reason, at least three washes, including rinses, should be made within 8 minutes, of which at least 6 minutes should be devoted to scrubbing. Only light pressure should be applied to the brush--not sufficient to bend the bristles out of shape of to scratch or erode the skin. Rinse thoroughly and monitor.

c. Apply lanolin or hand cream to prevent chapping. Chemicals may be used for cleansing other parts of the body or the hands, if the above procedures do not successfully remove the contamination. There are two processes in general use. Procedure (1) outlined below has been used sucessfully for heavy contaminations. However, if (1) is unsuccessful,

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it may be followed by (2), Parts A and B.

(1) Apply a liberal portion of titanium dioxide paste to the hands. Work this paste over the affected areas and adjacent areas of the skin for at least 2 minutes. Use water, sparingly, to keep the paste moist. Rinse with warm water, and follow by thorough washing with soap, brush, and water. Be sure that no paste is allowed to remain around the nails. Monitor. Repeat the entire process if necessary.

It should be noted that the condition of the titanium dioxide paste is very important. In order to be effective, the paste must be prepared by mixing precipitated titanium dioxide (a very thick slurry, never permitted to dry) with a small amount of lanolin.

(2) Part A. Mix equal volumes of a saturated solution of potassium permanganate and 0.2 N sulfuric acid. Pour this over the wet hands, rubbing the entire surface and using a hand brush for not more than 2 minutes. (Note: this application will remove a layer of skin if allowed to remain in contact with the hands too long; consequently, the time stated here should not be exceeded for any single application.) Be sure that all areas are thoroughly covered. Rinse with water and proceed as follows:

Part B. Apply a freshly prepared 5-percent solution of sodium acid sulfite ($NaHSO_3$) in the same manner as above using a hand brush and tepid water for not more than 2 minutes. Wash with soap and water, and rinse thoroughly.

The above procedure may be repeated several times as long as the permanganate solution is not applied for more than 2 minutes during any

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one washing. Applications to other parts of the body than the hands may be facilitated by the use of swabs steeped in the solutions. Lanolin or hand cream should be applied after washing.

A hand decontamination kit should be maintained in each wash room associated with the decontamination facility.

In the event that the skin is broken in accidents while working with radioactive substances, immediate action should be taken to remove possible contamination. Wash the wound under large volumes of running water immediately (within 15 seconds) and spread the edges of the gash to permit flushing action by the water. Light tourniquet action to stop venous return (but not to restrict arterial flow) may be desirable to stimulate bleeding. Report all wounds to the responsible medical or radiological safety officer as soon as emergency precautions have been taken.

Contaminated clothing may be laundered in the conventional manner using commercial household detergents. In the event excessive contamination levels (use guide lines given in Figure 6) are experienced, the clothing should not be released to commercial laundries, but laundered in facilities provided in the change station. In the event high levels of contamination persist, repeated laundering will be required.

Shoes are not ordinarily launderable and, if contaminated to above permissible levels, are usually stored and made available for reentering the contaminated area.

Contaminated rubber clothing, such as boots, overshoes, and rain gear often may be decontaminated by water flushing with hose.

Decontamination of aircraft can be readily accomplished by high pressure hosing with water and detergent. A common practice employed by

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the Air Force is to use a tank truck with a 400 gallon capacity capable of delivering the detergent solution under 200 pound per square inch pressure to wash down the aircraft. A mixture of 5 pounds sodium hydroxide, 4 pounds citric acid, and 32 pounds naconal per 400 gallons of water has been found to be very effective. Steam cleaning is also very effective. Removal of the aluminum oxide surface using a 5% solution of muriatic acid (commercial hydrochloric) is extremely effective but only recommended in very persistent cases of contamination.

Aircraft parts may be decontaminated by standard methods including, scrubbing with water and detergent, organic solvents, and/or steam cleaning. Ultrasonic cleaning techniques is also very effective on small parts.

Disposal of the wash water can create a problem but for the most part adequate dilution usually occurs when it is emptied into the sewerage system of the main facilities. Guide lines for the release of the contaminated waste water into uncontrolled areas are given in Figure 5. On rare occasions, tank storage facilities may be required so that controlled release of the contaminated water may be exercised.

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SUMMARY

The existence of fission fragment debris trapped above the tropopause will continue to be a source of contamination to aircraft operating at those altitudes for an indeterminate length of time. If the nuclear testing programs are resumed, the stratospheric reservoir will be replenished. However, prior to the termination of the test program, the stratospheric level of contamination remained essentially constant for the past several years. Thus, it is not expected that the contamination problem would increase significantly in magnitude.

The radiation guide lines suggested are both reasonable and conservative. They are based on the NCRP recommendations, the age of the fission products, and where applicable, the critical body organ. Guidance is given for permissible levels of beta-gamma levels for both uncontrolled and controlled exposure, permissible air concentrations for the uncontrolled area, permissible water concentrations for the uncontrolled areas, and permissible levels of removable activity.

Experimental studies have demonstrated clearly that the radiation hazard to maintenance personnel who work on aircraft contaminated with mixed fission products can be adequately defined by a simple beta-gamma survey of the immediate area. The contribution to their total radiation dose from inhalation of the resuspended debris or ingestion from hand contamination are unimportant ranging from factors of 100 or more below that contributed by external dose.

Aircraft that fly in the regions of the stratospheric contamination

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reservoir will encounter some contamination build-up. The levels will be such that it is highly improbable that anyone would ever receive exposure in excess of the permissible limits, either from external radiation or from internal uptake of the radioactive isotopes.

In the present situation, it is inconceivable that decontamination would ever be required on the basis that the existing radiation levels represent a health hazard. However, if policy dictates that it should be accomplished, techniques for personnel, aircraft, and material decontamination are outlined.

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