

# A MODULAR APPROACH FOR ASSESSING THE EFFECT OF RADIATION ENVIRONMENTS ON MAN IN OPERATIONAL SYSTEMS

(The Radiobiological Vulnerability of Man During Task Performance)

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## INTRODUCTION

Whether a manned system is designed for peaceful exploration or military ventures, it stands a good chance of encountering radiation environments. These environments contribute a definite hazard to these manned missions and consequently must be analyzed in regard to mission impact. This impact on man can best be assessed by use of a model designed to incorporate all of the variables having a contribution to the problem of concern.

## A STATEMENT OF THE PROBLEM

A practical approach to the assessment of the vulnerability of aircrews and other personnel in operational systems has long been a difficult problem. There are various radiation environments which a system may encounter. For example, military systems may be exposed to nuclear weapons, reactors and natural space radiation. A nuclear weapon detonation gives off specific radiations of biological significance. These radiations interact with the atmosphere and are continually altered in type, number, and energy (flux and spectrum) until they impact on an object. The radiations of concern are prompt neutrons, prompt gamma rays, secondary gamma rays, and fission product gamma rays.

The space radiations of biological significance include the trapped electrons and protons of the Van Allen Belt; the protons of solar events and the galactic cosmic rays<sup>1</sup>. In order to assess any radiobiological problem, one must have an accurate knowledge of the flux and spectrum of the radiation impinging on the system. Radiation transport computer codes and models must be developed or adapted to obtain the most accurate and efficient method for use in specific cases.<sup>2</sup>

The biologically significant radiation parameters reaching man within the system must be transported through the system's materials and into the man. Various materials transport codes and models are available to obtain the most effective method for use in dose determination. These in-turn must be linked to a recently developed computerized anatomical man model to obtain dose factors at significant radiobiological points within the man in specific operational situations.<sup>3</sup> Data from anticipated operational situations must then be inter-

preted in terms of appropriate radiation dose parameters such as: total dose, dose rate, quality factor, etc. These data can then be linked to available performance response data to enable computer modeling of the probability of a performance response occurring versus time of onset.

The final outcome should be a computer model designed to assess the mission impact for personnel in operational systems exposed to radiation environments

## APPROACH TO THE PROBLEM

A modular approach has been developed to provide a vehicle for interrelating the many variables inherent in a radiobiological problem encountered by an operational system. This modular design is developed within a multi-layered matrix which includes space vehicles, air breathing, systems, and ground and water based systems. The matrix is divided into three sections containing those modules which (1) define the environment, either natural or man-made, (2) transport the environment to the system, (3) transport the impinging environment through the vehicle to man within the system, (4) transport the radiation to the organ of concern within the man, (5) obtain radiobiological factors such as dose, dose rate, quality factor, etc., and (6) link these factors with the appropriate radiobiological data to properly assess the effect on man's performance capability or predict any resulting performance decrement.

## THE MATRIX

### Section A - Environmental Transport

The first section of the multi-layered matrix is the environmental transport section. This section deals with defining the radiation environment either natural or man-made.<sup>4,5</sup>

These radiation environments are as follows:

1. Man-made radiation:
  - a. Nuclear Weapons
  - b. Incident radiation from nuclear

power devices, primarily leakage neutrons and gamma radiation.

## 2. Natural Radiations:

a. The natural radiations which are relatively stable in space and time (i.e., galactic cosmic rays and magnetically trapped electrons and protons in the inner Van Allen Belt out to 3000 miles.)

b. The natural radiations which are variable with space and time, primarily solar flares and soft trapped radiations in the outer Van Allen Belt.

These sources have specific radiations of biological significance. These radiations interact with the ground, atmosphere or space and are continually altered in type, number, and energy (flux and spectrum) until they impact on an object. In order to assess the radiobiological problem, one must have an accurate knowledge of the flux and spectrum of the radiation impinging on the operational system. There are currently available several radiation transport computer codes and models. These have been surveyed to determine the most accurate and efficient combinations for use in specific cases, and have been documented using a standard format to facilitate selection of the best available code or codes for use on specific problems.<sup>2</sup>

### Section B - Materials Transport

Section B of the matrix is designed to handle the transport of the radiation environment from its point of impingement on the system until it reaches man within the system. Various materials transport codes and models are being evaluated to obtain the most effective method for use in dose determination. These in-turn are being linked to a recently developed computerized anatomical man model to obtain dose factors at significant radiobiological points within the man in specific operational situations.<sup>3</sup>

### Section C - Performance Response Assessment

This third section of the matrix deals with assessing mission impact for personnel in operational systems exposed to radiation environments. Data from anticipated operational radiation exposure situations will be interpreted in terms of appropriate radiation dose parameters such as: total dose, dose rate, quality factor, etc. These data will then be linked to available performance response data to enable computer modeling of the probability of a performance response occurring versus time of onset. Several models will be developed or evaluated to obtain the optimal approach for taking a radiation dose in man and linking with performance response data. Areas to be investigated include techniques for extrapolating data from animals to man; literature search including reports of accidental human exposures; reports of therapeutic human irradiation; studies of victims of the Hiroshima and Nagasaki nuclear attacks; studies of animal irradiation experiments; and theoretical papers describing the models now available for estimating radiation injury. Data from the literature will be examined to determine common factors and correlated effects, especially those

which may be correlated with other effects to permit extrapolation of the results of animal experiments to the prediction of human response. This information will be summarized, input to the appropriate computer model and presented in a format for vulnerability analyses of operational systems.

## PROGRESS

The Biomedical Branch of the Analysis Division of the Air Force Weapons Laboratory is primarily concerned with the vulnerability assessment of man in USAF systems; therefore, our effort to date is basically in relation to aircraft within the earth's atmosphere or the atmospheric layer of the multi-layered matrix. However, it is obvious that only Section A of the matrix is significantly different among the various layers while sections B and C are virtually identical with only those differences which the various operational systems themselves contribute.

I will use USAF operational systems in the atmosphere exposed to nuclear weapons as the examples of the actual workings of the matrix, because we have done the most work and are the most knowledgeable in this area.

## FEASIBILITY OF THE MODULAR APPROACH

Discussing the modular approach to assessing man's vulnerability in operational systems and the multi-layered matrix we have developed, one must consider the feasibility of such an approach. In doing this, we must consider the radiation environments and a system which may potentially be exposed to nuclear weapons. Therefore, we take a weapon, let's call it a "Mark-X", and we detonate this weapon in our computer.

What sort of things do we need to know about the weapon? We need to know the type of radiation, the intensity of the radiation and the time array of delivery and the energy spectra. In order to understand these, we need to know the yield of the weapon, the type of weapon such as fission or fusion and the design of the weapon. This radiation passes through the atmosphere and consequently we need to know the surrounding environment; such things as the pressure, sensitivity, composition of the atmosphere and exponential variations. We need to know the altitude at which the weapon was detonated and then the position of the receiver such as altitude and horizontal range from the weapon.

Other factors of concern are significant interfaces such as air-ground and air-space. Air-ground, because of absorption and reflection, air-space because of leakage from the atmosphere. In addition, we need to know the burst altitude in regards to the surface and the type of air that we assume; e.g., a homogeneous atmosphere, a layered atmosphere or an exponential atmosphere. Also, we must consider whether our receiver is moving or fixed. In transporting the weapon radiation through the environment, we need to know what type of transport we are going to use, elemental cross-section data, reactions involved, build up factors and so forth. Or, in other words, we have to have sophisticated mathematical models and computer codes to obtain an accurate transport.

Upon reaching our target, other things to consider would be angle of incidence of the radiation, energy deposited, material in which the energy is deposited, accumulative errors during the transport and flux to dose conversion factors.

In considering the feasibility of section A of the matrix, we took a make believe weapon and its output in terms of prompt neutrons, prompt gammas, secondary gammas, and fission product gammas and used available computer codes to transport these outputs up to the aircraft system. Initially, we were not interested in the accuracy of our procedure, only in the feasibility. However, we did attempt to look at other overriding factors. For instance, if blast, thermal or electronics kill mechanisms were primary and destroyed the aircraft, we no longer had a radiobiology problem. Therefore, we attempted to determine kill envelopes for some of these other factors. As applied radiobiologists, we did not want to be doing vulnerability studies on purely academic situations.

The feasibility analysis of section B of the matrix, the materials transport area, resulted in discussions centering on the necessity of obtaining attenuation factors either by sectoring the system or by some other means. We elected to use the sectoring procedure.<sup>1</sup> That is, to use a vehicle that had been sectored into various solid angles. We did not have a sectored aircraft available so, having been in the space business for some time, we decided to use a Gemini spacecraft, on which we had good sectoring analyses. We took Gemini out of space, brought it down into the atmosphere and called it an airplane. Using Gemini's various solid angle sectors, we managed to take the impinging radiation and transport it by the use of materials transport codes to man within the system. Concerning man, we had developed, for NASA, a very sophisticated computerized anatomical man model which had several hundred solid angle sectors.<sup>3</sup> For the purpose of the feasibility study, we took the midline gut dose, assumed it was the vomiting dose, and transported the environment impinging on man into the midline of the gut. In using the computerized anatomical man model, we actually handle the problem as a materials transport situation.

The next step is linking the dose received by man to a performance response. This part of the matrix system is the most difficult to develop. The performance response we used for descriptive purposes was vomiting because everybody knows what vomiting is and it is one of the few performance response factors on which we have some human data. Thus, we took the dose to the midline gut and linked it with human vomiting data in such a way that we could graph the probability of the performance response occurring versus time post exposure.

We thus proved that our approach was at least feasible. In other words we can link from A through C of the matrix. However, that really doesn't solve the final problem for us. That problem being: "Is it really practical to use this modular approach in assessing man's vulnerability?" This can only be done by applying the matrix to an actual system. It happened that the Air Force was conducting studies at that time

on the F-106 fighter-interceptor aircraft and were very interested in obtaining sufficient data to include man in their survivability/vulnerability analyses. They had a list of weapons that they expected the aircraft to be exposed to in a nuclear situation. We picked three of the weapons representing worst case, best case and an intermediate case situation.

In attempting to transport the weapons radiation in a more realistic manner than we had done in the feasibility study, and with a greater concern for accuracy, it became obvious that the computer transport codes available to us were not satisfactory. We had a choice of taking these codes and patching the various sections of several of the codes together or of developing an entirely new code. Development is very time consuming and expensive while adapting various sections of several codes was not a practical approach either. Therefore, we hit on a compromise wherein we developed essentially a new code but which used two other codes as basic models. One of these was a large data base code and the other a curve fit code. By using the available data base code, we were able to rebuild the curve fit code so that it was capable of doing most of those things we wanted done; such as, transporting prompt neutrons and gammas, secondary gammas, and handling fission product gammas in a realistic way with a minimum amount of computer time and with an output which could be directly input to materials transport codes. At the same time, this new code could be added to or subtracted from in a modular manner to handle other types of transport problems. Another factor, probably as important as all the rest, was that the learning time to run this code was very short.<sup>2</sup>

Therefore, knowing the weapon's characteristics and using the new code, we were able to properly transport the radiation from the weapons, through the atmosphere, to the aircraft system, in this case the F-106.

In the feasibility study we did not have a sectored aircraft so we used the Gemini spacecraft. The argument still remained concerning what methods to use in developing attenuation factors. Because of our experience in flying unmanned satellites in space, we fell back on an old idea; that is the radiation scanning or gamma scanning of a system to obtain attenuation factors.<sup>1</sup> In this whole controversy, it turns out that the only way to prove that you can take short cuts is to do it the hard way first. Therefore, we tried to obtain an F-106 and gamma scan it. There was no F-106 available to us at the time, but we could get an F-102 which has a very similar configuration, mass and distribution to the F-106. After analyzing our gamma scanning results, we determined that these factors would be fine for transporting gammas but not satisfactory for neutrons. Thus, we performed a neutron scan of the F-102 system. Using the results of these two efforts, we then were able to transport the radiation impinging on the system, through the system and to man within the system. We were then through another crucial part of the effort in establishing the practicality of our approach.

We used our anatomical man model for transporting our environment to organs of concern within the body. This model had been developed basically for transporting space radiations such as protons and electrons and we found that we had difficulty

stuffing neutrons through it. However, by proper manipulation we were able to transport the impinging radiations into the midline gut and midline brain of the man. Using our dose determinations at these points, we linked to available radiobiological research data.

Assuming the gut dose was the vomiting dose, we plotted the probability of this response occurring versus time of onset; and assuming that the brain dose was the incapacitation dose, we plotted the probability of early transient incapacitation and permanent complete incapacitation versus time of onset. This information not only allowed us to prove the practicality of our modular approach but also gave for the first time readily useable data to be applied to an operational aircraft system. While performing the above, we did one other thing which now forms the basis for our ongoing studies. At each junction within the matrix, we listed: (1) the variable encountered, (2) the assumptions we made about that variable and (3) our estimation of that variables contribution to our error.

In developing the matrix and in assessing the feasibility and practicality, of our modular approach, we had many basic problems as we worked through the program: (1) obtaining weapon information was not easy, just as it took us a decade to obtain reasonable space radiation environment data, there is quite a bit of refinement to be done to assure us that the radiation environment we are using is accurate. (2) We are still not satisfied with the transport codes that we have and we are trying to refine and update them. (3) Another concern is the atmospheric condition at the time of detonation of a weapon. Our calculations indicate that we could have an order of magnitude error if we only considered a mean spring day at 40° latitude as opposed to a typical winter day at a higher latitude. (4) The radiation impinging on a system does not impinge in a plane or perpendicular to a plane. There are many angles of incidence. These need to be considered in our procedures in order to assure that we have a handle on this possibly very important factor. (5) Radiation scanning both gamma and neutron, of systems such as the B-52 or the proposed B-1, must also be done but, hopefully, in the long run, we will be able to obtain our attenuation factors by analytical analyses of blueprints of the systems. (6) Those transport codes that we have used also need to be refined and updated. (7) The computerized anatomical model of man is excellent for handling space radiations but still unsatisfactory for handling weapons environments. Therefore, the model must be altered and adapted for this purpose.

Various dose parameters must be considered if you are going to link properly to available research data; that is, dose, dose rate, depth dose profile, quality factors and multiple exposures, to name a few, must be considered in any practical application of the model. We are fortunate in the case of dose rate in a weapons situation in that good biological research data is available to indicate that the total dose received from a weapon, delivered in less than a second, does not affect the biological response. In other words, the dose from a weapon is instantaneous and we only have a single dose rate. For reactor

environments or fall-out environments, we will have to handle varying dose rates. A depth dose profile is important and our anatomical man model allows us to obtain isodose contours within the body. However, this is done at the expense of a great amount of computer time. We have managed to short cut this to some extent. If we only consider the dose to those organs which produce a given response in a specific time period, then we save a lot of time by transporting the radiation so that we obtain the dose only at those organs.

Quality factor, that area of constant controversy among radiobiologists, can best be handled in this case by linking the data of an environment similar to the actual situation. In other words, if you have a weapon output transported to your man, where impinging on the man is a particular neutron to gamma ratio, you can link with the research done with this same neutron to gamma ratio, and, consequently, avoid many of the problems associated with the effect of quality factors. In section C of the matrix, where we graph the probability of response occurring versus time post exposure, we must eventually consider other variables. There are the non-performance variables such as age, whether the individual has eaten recently or not, the psychological makeup and so on. All of these will affect the shape of your curves. There are also the performance variables--early transient incapacitation, diarrhea, motor response changes, audio and visual capacity changes and so forth will affect the response and shape of the curves.

#### SUMMARY

A modular approach for assessing the affect of radiation environments on man in operational systems has been developed. The feasibility of the model has been proved and the practicality has been assessed. It has been applied to one operational system to date and information obtained has been submitted to systems analysts and mission planners for the assessment of man's vulnerability and impact on systems survivability. In addition, the model has been developed so that the radiobiological data can be input to a sophisticated man-machine interface model to properly relate the radiobiological stress with other mission stresses including the effects of a degraded system.

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