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A SIMULATION MODEL FOR ANALYZING REENTRY VEHICLE/ANTIBALLISTIC MISSILE ENGAGEMENTS

THESIS

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THESIS

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Preface

An effort of this magnitude cannot be accomplished solely by the authors. Our thanks must go to those who helped: Dana Spears and Clark Myers of the USAF Ballistic Missile Office for timely information and being willing to spend their own precious time to help; Paul Auclair for the discussions on ICBM accuracy; Larry Skapin of the Strategic Air Command (XPQO) for information and direction; Major Dan Fox for constructive criticism and advice on improvement; Dr. Charles Bridgman for spending his valuable time reviewing the text; and Lt Col Tom Clark, our advisor, for giving us the freedom to define our own goals, and providing the analytical techniques to ensure we achieved them. Finally, we must thank our wives for the support that we have received over the last few months and during the years of marriage. Kay and Pat, you made it possible.

Carl L. Critchlow
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Abstract

The subject of this thesis is the system consisting of the engagements between attacking intercontinental ballistic missile (ICBM) reentry vehicles (RV) and a defending ballistic missile defense system. The thesis presents a brief overview of the actual system before proceeding with the development of a computer simulation model designed to aid analysis of the system. The primary language of the main program is SLAM; the supporting programs use FORTRAN V. The RV/Antiballistic missile (ABM) system is modeled as a network through which the RVs flow. The capabilities of the RV with regard to yield and accuracy can be set to the user's desires as can the vulnerabilities of the RV to the two primary kill mechanisms considered, X-ray and neutron radiation. The ABM system consists of a two-tiered, layered terminal defense system with high altitude (70,000 - 150,000 feet) and low altitude (10,000 - 70,000 feet) interceptors. Interceptor yield and accuracy are changeable. Either layer can be activated or deactivated, singly or together, to permit flexibility in the comparison of actual or hypothetical systems. An example simulation is accomplished to demonstrate model operation and permit systemic analysis. The thesis also contains a User's Manual for those interested in using the model.

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I Introduction

General Situation and Importance

In their 1980 report on military posture to Congress, the Organization of the Joint Chiefs of Staff collectively stated:

> The intercontinental ballistic missile (ICBM) force provides flexibility for employment throughout the spectrum of nuclear conflict--from limited options to full-scale retaliation. The combination of responsiveness, accuracy, reliability, rapid retargeting capability, and assured penetration makes the land-based missile well suited for attack options where promptness, minimum collateral damage, and high confidence of success are paramount. The flexibility of employment which the ICBM force offers the National Command Authority is of great importance in nuclear planning (Ref 10:41).

In addition to the capabilities listed in the statements above, the ICBM force has unique characteristics which contribute to the vital diversity of the strategic Triad of bombers, ICBMs, and sea-launched ballistic missiles (SLBM). These unique characteristics include the Soviet perception of ICBM importance, high alert rates, low operating costs, a time-critical hard target capability, and defense suppression (Ref 24:15).

In considering the importance of the ICBM contributions to the Triad and strategic stability, the perceptions of the Soviets must be considered. Traditionally, they have concentrated the great majority of their strategic firepower in their ICBM force. Their massive research and development efforts and deployment plans, including four new ICBMs, give dramatic evidence of the importance they continue to attach to the ICBM force. The Strategic Arms Limitation negotiations of the 1970s granted the Soviets' ICBM numerical and size superiority. They clearly feel that the ICBM is vitally important in maintaining perceived essential equivalence (Ref 24:15).

The high alert rates of the ICBM force are another clear indicator of the importance of the ICBM. Normally, almost 100 percent of the U.S. ICBM force is in instant readiness for launch, compared with about one-fourth of the bomber force, and somewhat less than 50 percent of the SLBMs. The fact that this high alert rate is maintained with only about one-eighth of the total operating budget of the entire Triad also buttresses the case for the significance of the ICBM (Ref 24:15).

Because of their accuracy and instant readiness, ICBMs have a time-critical hard target capability, as well. Combined with their short time of flight, the ICBMs can both limit the destruction of this country in a full-scale nuclear exchange, by destroying enemy forces before they can be launched, and act as a force multiplier for other parts of the Triad. The ICBM can be used in a defense suppression role, thereby enhancing the effectiveness of the bomber force.

In summary, the ICBM offers vital contributions to the strategic Triad of forces and the maintenance of political stability. But the survivability of the ICBM has recently been questioned. Many experts feel that the fixed locations of the ICBMs make them vulnerable to attack. This lack of prelaunch survivability has a severe impact on the credibility of the ICBM deterrent. Correcting this deficiency continues to be the highest priority strategic initiative (Ref 24:3). The billions of dollars that will be spent to make the MX survivable will be wasted, however, unless the survivability of the ICBM is ensured during penetration of enemy defenses. There are two sides to ICBM credibility: the ICBM must be capable of withstanding an enemy attack, and it must be capable of striking enemy targets with a high probability of success. The U.S. government is making massive expenditures to ensure the first aspect but the second is in doubt.

An effective ballistic missile defense (BMD) system can severely degrade or neutralize the deterrent capability of the ICBM force. Opponents of the Safeguard/Sprint BMD systems of the 1960s characterized the defense as "trying to hit a bullet with a bullet." Technological advances have invalidated this metaphor. The Soviets clearly believe that the technology is at hand to deploy a credible and effective ballistic missile system (Ref 6).

Test and installation of improved BMD systems are now prohibited by the Anti-Ballistic Missile (ABM) Treaty of 1972.

As a result, the level of U.S. concern about BMD has fluctuated. An opportunity exists for ABM treaty reconsiderations in 1982. At that time, the United States and/or the Soviet Union can propose modifications to or continue with the treaty.

The Soviets could also decide to install an improved BMD system unilaterally. That is, they could simply refuse to engage in treaty negotiations, allow the current treaty to lapse, and begin deployment of an improved ABM system. Since deterrence relies on the perceptions of an enemy, it is only necessary for the enemy to believe that their defensive network is effective for deterrence to fail. As a result, the deployment of such a system could significantly affect the credibility of the United States' ICBM deterrent force and could result in the ultimate in political instability, the failure of deterrence and the occurrence of nuclear war.

The analysis of the impact that such a deployment would have is an extremely complex problem. Analytical solutions do not exist and current computer simulation models are too large and unwieldy, not comprehensive enough, or biased by the designer's frame of reference.

Literature Review

As illustrated by Figure 1, a wealth of analytical approaches existed as early as 1968 to aid the planner in solving the general problem of allocating missiles to targets.

	WEAPON COMPLEX		
	SCOPE	REACH	COMMITMENT
A	ONE WEAPON TYPE / NO PEN AIDS	ALL WEAPONS REACH ALL TARGETS WITHOUT DEGRADATION	SIMULTANEOUS ASSIGNMENT / OF INTACT FORCE
B	ONE WEAPON TYPE / PEN AIDS	ZERO-ONE INCIDENCE MATRIX WITHOUT DEGRADATION	SIMULTANEOUS ASSIGNMENT / OF PROBABIL-ISTICALLY REDUCED FORCE
C	N>1 WEAPON TYPES / NO PEN AIDS	INCIDENCE MATRIX ENTRIES ARE PAYLOADS OR KILL PROBS	SEQUENTIAL ASSIGNMENT / OF INTACT FORCE
D	N>1 WEAPON TYPES / PEN AIDS	FOOTPRINTS, PAYLOAD AND ACCURACY DEGRADATIONS	SEQUENTIAL ASSIGNMENT / OF PROBABIL-ISTICALLY REDUCED FORCE
E			
F			

Fig 1. Compilation of Analytic Approaches (Ref 12:338)

TARGET COMPLEX		
SCOPE	VALUE	DEFENSE
INDEPENDENT / POINT TARGETS	ALL TARGETS HAVE EQUAL VALUE	NO DEFENSES
INDEPENDENT / AREA ± POINT TARGETS	PRIORITY RANKING OF TARGETS	SPECIFIED TERMINAL DEFENSES
DEPENDENT / POINT TARGETS	CARDINAL VALUE SCALE	SPECIFIED AREA DEFENSE INVENTORY, NON-PREFERENTIAL STRATEGY
DEPENDENT / AREA ± POINT TARGETS	INDIRECT AND DIRECT VALUED TARGETS	PENETRATION PROBABILITIES GIVEN AT EACH TARGET AND/OR DEFENSE ISLAND
	MULTIPLE VALUE SCALES	TERMINAL INVENTORY KNOWN, ALLOCATION UNKNOWN
		TOTAL AREA INVENTORY KNOWN, PREFERENTIAL DEFENSE

Fig 1. Continued

ENGAGEMENT MODEL	DAMAGE MODEL	ALGORITHM
PERFECT OFFENSE / PERFECT DEFENSE (OR NO DEFENSE)	ZERO-ONE DAMAGE / N PENETRATORS KILL TARGET	TECHNIQUE: AN: ANALYSIS GA: GAME THEORY MA: MANUAL GR: GRAPH THEORY LP: LINEAR PROG. NL: NONLINEAR PROG. DP: DYNAMIC PROG. SE: SEARCH MC: MONTE CARLO LM: LAGRANGE MULTIPLIERS
P_{ij} = PROBABILITY ith WEAPON PENETRATES AND KILLS jth TARGET IS GIVEN		
OFFENSE IMPERFECT / DEFENSE PERFECT	ZERO-ONE DAMAGE / PROB. PENETRATOR KILLS TARGET	
OFFENSE PERFECT / DEFENSE IMPERFECT	PARTIAL DAMAGE / FUNCTION OF NO. OF PENETRATORS	PROPERTIES: IS: INTEGER SOLUTION CS: CONTINUOUS SOLUTION OP: OPTIMALITY PROVEN NO: NEAR-OPTIMUM TS: TWO-SIDED SS: SMALL SCOPE LS: LARGE SCOPE
IMPERFECT OFFENSE / IMPERFECT DEFENSE	PARTIAL DAMAGE / FUNCTION OF NO. OF PENETRATORS, ACCURACY, REL.	
	MIXED WEAPON ATTACK	

Fig 1. Continued

The so-called missile allocation problem has four discrete parts according to Matlin: the weapon complex, the target complex, the engagement model, and the damage model (Ref 12: 338).

The weapon complex portion of the problem can be described by three characteristics: scope, reach, and commitment. The scope of the weapon complex refers to the number of different RV types considered and whether or not penetration aids are considered. Weapon reach refers to which weapon can reach which targets and with what degradations in accuracy and payload. Weapon commitment policy indicates the number of waves launched, quality of damage assessment, and weapon availability uncertainties. The target complex is also characterized in three categories. The scope of the target refers to dependence or independence of point, area, and collateral targets. Target value defines an appropriate measure of effectiveness of a given missile allocation. The target defense type may be terminal, area, or preferential (Ref 12:337).

Figure 1 represents 36 different analytic approaches that existed in 1968. However, none of the models represented were comprehensive in all areas. Generally, if the weapon complex portion of the model was sophisticated, the target complex or the engagement model was simplified (Ref 12:337). In addition, these analytic techniques are aimed toward analyzing a different problem than determining the impact of ABM deployment. The complexities and stochasticities of the problem are such that no analytical technique exists to approach the problem.

In an effort to remedy the shortcomings of the analytical approaches, some analysts turned to computer simulation. The U.S. Air Force's Multiple Engagement Model and the McDonnell Douglas Astronautics Company's ENGAGE model are examples of some current efforts in the area (Ref 22; 26). Current simulation models do not, however, adequately analyze the impact of ABM deployment. Some are not comprehensive in all areas of the problem. Those that embody most of the complexities are too large and unwieldy. Some models are also biased by the designer's frame of reference or parochialism.

This is not intended to degrade the efforts of previous modelers. On the contrary, their models were and are worthwhile because, in the absence of analytic techniques, computer simulation offers the best approach to the problem. In the first place, since any postulated BMD system must be hypothetical, analysis by experimentation with the actual system is not possible nor practical. Secondly, the process of development of a simulation model leads, by itself, to a fuller understanding of the actual system and, thus, better analysis. Finally, the complexities and uncertainties of the actual system have prevented the development of analytical solutions. As an example of the complexity of the issues involved, consider the deployment of the Advanced Maneuvering Reentry Vehicle (AMARV).

The AMARV, unlike current reentry vehicles (RV) that essentially freefall to the target area, can maneuver after separation from the ICBM that delivered it. This maneuvering capability theoretically increases the possibility of successful penetration of an ABM defense network. In order to maneuver, guidance equipment is required inside the AMARV which displaces some of the nuclear material that could be carried on board a nonmaneuvering RV, resulting in smaller weapon yields (Ref 1:43-45). The complex trade-off question is then: Should the AMARV be deployed in light of its increased probability of successfully penetrating ballistic missile defense systems or will its smaller yield, when compared to current RVs, result in less target destruction regardless of its penetrability? Current techniques, both analytical and using computer simulation, are simply incapable of supplying an answer to questions such as this. The model contained in this thesis is specifically designed to rapidly provide information to help answer such difficult questions.

Problem Statement

The system under consideration consists of three major components: the attacking ICBMs with their RVs and penetration aids such as decoys and chaff, the defending ABM subsystem, and the target area. In order to analyze the effects of improving the defenses, the complexities of the entire system must be embodied in a model. For example, parameters affecting the defense, such as weapon yields and accuracies, intercept altitudes, and command and control system reliabilities, must be included. The performance requirements of the model can also be developed in light of the questions the model can be used to answer. Along with the previous question concerning AMARV deployment, alternative RV designs can be evaluated, competitive defense systems and strategies can be compared, or new penetration aids tested. In light of the flexibility required for a model that must provide information to help answer questions such as these, and the extreme complexity of the actual system, the following problem statement is appropriate:

> Develop a computer model of the RV/ABM engagement system that has the flexibility to vary the parameters affecting the capabilities of the three major components of the system: the attacking reentry vehicles and penetration aids, the defending ballistic missile defense network, and the target area. Combined with this flexibility must be the sophistication necessary to analyze the complex interactions between the participants in all parts of the system.

This problem statement leads to the objectives of this thesis as outlined in the next section.

Objectives

Claims for RV and ABM capabilities are advanced by all parties to the debate. The first objective of this thesis is to provide a model that allows the comparison of different RVs, ABMs, and defense and offense strategies. The key word for this model is flexibility. It must be able to handle variation in parameters, capabilities, and strategies. The second major objective of this thesis is a User's Manual that will provide an indepth explanation of the model and instructions on operation for anyone who desires to use the model. The final major objective is an illustrative exercise of the model that demonstrates both the capabilities of the model and the interactions of the actual system. This example also permits the development of some conclusions concerning the system.

The Engagement Regime

The system that is the subject of this thesis involves the encounters between attacking ICBMs, and the weapons carried, and defending ABMs. These engagements take place in the atmosphere above the target area. The ICBMs deploy individual reentry vehicles (RV) which enter the atmosphere along with the chaff and decoys deployed with them to deceive the defensive radars. The ABM radars can begin to discriminate the threat objects as to actual type after the atmospheric drag has stripped the chaff screen away. Final identification of threat type (RV or decoy) takes place nearer the target (Ref 13:12-13). Figure 2 shows an example altitude of 150,000 feet for this final identification point. This point also marks the upper boundary of the endo-interceptor region or that region where attacking RVs are engaged only by endo-interceptors. The lower boundary of this region is assumed to be the minimum altitude at which the endo-interceptor can successfully engage the attacker. Figure 2 illustrates this boundary at 70,000 feet (Ref 6).

Current ABM interceptors employ the effects of nuclear weapons to destroy the attacking RVs. These effects include X-rays, neutron radiation, and blast. Only the first two effects are of primary concern because they have the farthest lethal radii (Ref 4).

In a vacuum, X-ray radiation is lethal at a greater distance than neutron radiation, all other factors being equal. However, X-rays are more quickly attenuated by the atmosphere than neutrons. As a result, the primary kill mechanism throughout the majority of the endo-intercept (EI) region is X-ray radiation because of the low density of the atomosphere. The point intercept (PI) region, on the other hand, has

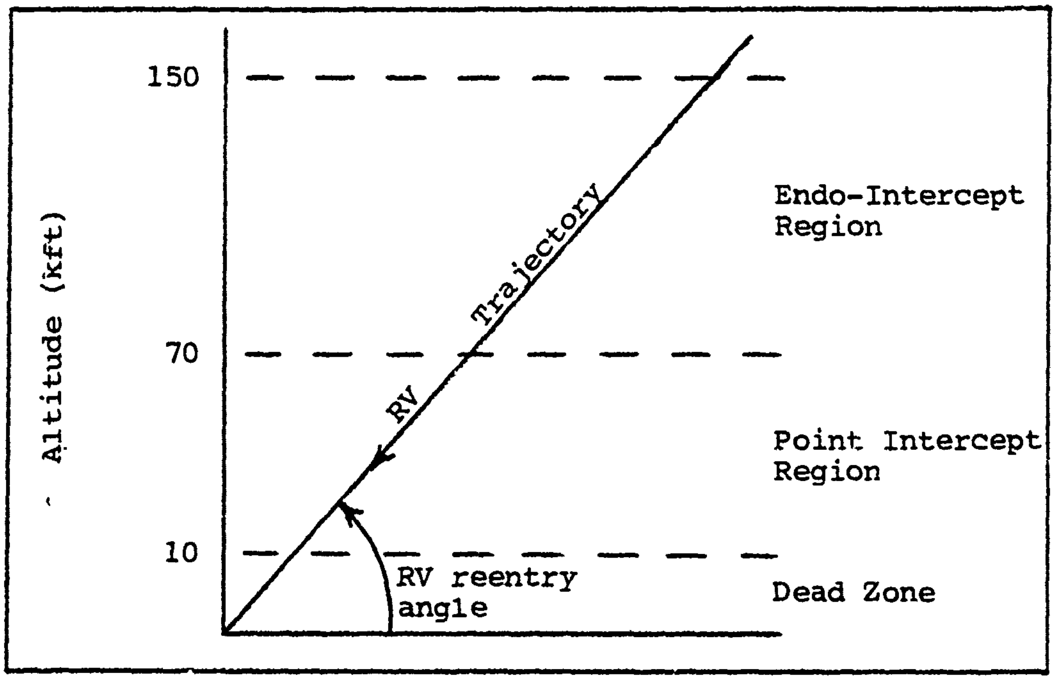

Fig 2. The Engagement Regime

denser air and the dominant kill mechanism is neutron radiation or fluence.

The top of the PI region is marked by the maximum operational altitude of the PI interceptor. Intercepts can take place anywhere in the region. The lowest point of the PI region is the minimum engagement altitude of the interceptor and results in the Dead Zone depicted in Figure 2, a region of no engagements.

Methodology

The research methodology employed in this thesis falls within the framework of the system science paradigm as outlined in Management Systems - Conceptual Considerations (Ref 20:295-305). The first step is the conceptualization of the system. In the conceptualization of the system, the relationships between the system components and how they interact are explored. A critical step in this phase is the development of a structural model of the system.

The second phase of the system science paradigm is the analysis and measurement phase. In this portion of the methodology, such topics as the selection of a computer language, the specifications of the model, and the standardization of the model results are dealt with. This definition of the desired output of the model leads to the third phase of the paradigm, computerization.

The computerization phase of the methodology deals with the translation of the concepts of the actual system (the real world) and the structural model into a computer model that will satisfy the first objective of this thesis.

<u>Overview</u>

After providing a brief explanation and description of the actual system in Chapter II, the remainder of this thesis deals with two major topic areas: the development of the simulation model in Chapter III and the illustration to potential users of the operation of the model in Chapter IV. The development of the system model is traced within the three phases of the systems science paradigm: conceptualization, analysis and measurement, and computerization. Both structural and parametric models are presented to aid in the illustration of the complex interrelationships between system components. Finally, the issues of model verification and validation are dealt with. During verification, the model is examined to ensure that it is behaving as intended. This is accomplished by a building block approach. First, each part of the model is examined separately to verify its correctness. Then, the parts are added one by one until the entire model has been verified. During validation, a two-pronged approach is followed. The objective of the first phase of the validation process is to ensure that the model coincides with the operation of the real system. That way, assumptions about the interrelationships of the model components are correct assumptions about the interrelationships of the actual system. The objective of the second phase is validation of the model from an empirical point of view. That is, prima facie evidence of validity is gained if the model is used to effect change. Once the model has been developed, verified, and validated, the next step is a demonstration of its operation.

Chapter IV of this thesis contains an example situation that the model is used to evaluate. A new RV is proposed and its effectiveness is evaluated in terms of its success in penetrating a hypothetical ballistic missile defense network and destroying a target area. The example also contains the statistical experiment necessary to analyze such a complex issue. The example is limited to hypothetical RVs and BMD systems because of the security classification of the parameters of actual systems. With the User's Manual contained in Appendix C, an analyst with access to actual system capabilities could easily evaluate real systems. The example simulation does demonstrate some of the capabilities of the model and illustrates the complexities and significant factors of the actual system. The statistical analysis leads to the conclusions and recommendations contained in Chapter V, the final chapter of this thesis.

II The System

Introduction

The system under consideration in this thesis is a hypothetical target area that is defended by an antiballistic missile system and attacked by ICBM reentry vehicles. In order to describe the system, the goals of the system's components are first presented. This is followed by an explanation of the three major components of the system, that is, the attacking RVs, the defending ABM system, and the target area. The assumptions made about the components in these explanations are central to the understanding of both the actual system and the model contained in this thesis.

The System Goals

Since all systems are goal oriented, the first step toward gaining an understanding of the system under consideration, and developing the system's structure, is an identification of the goals of the system. There are two opposing sides in this system, the attacking RVs, and the defending BMD and target area. Each side has goals. Figure 3 is an illustration of an assumed goal hierarchy for the attackers. The intent of Figure 3 is to express the idea that the attackers must first penetrate the defenses, the lowest level goal, and then inflict a specific level of damage in order to accomplish the highest level goal, removal of the opponent's war-making capability.

Remove the enemy's capability to wage war (highest level)

Inflict a specified level of damage
on the enemy's offensive forces

Penetrate enemy defenses to targets (lowest level)
(enemy offensive forces)

Fig 3. Attacking Force Goal Hierarchy

The assumed goal hierarchy for the defense is similar. This is illustrated in Figure 4 and reflects the same concept of goal ordering.

Retain offensive capability (highest level)

Restrict target damage to lowest level possible

Destroy as many attacking RVs as possible (lowest level)

Fig 4. Defending Force Goal Hierarchy

The two lower level goals of the defending force are accomplished by the defensive ABM network. The hypothetical target area is assumed to be a part of the opponent's offensive force, for example an enemy ICBM squadron. Thus, the defenses actually support the enemy's goal of offensive capability by preventing or restricting damage to those offensive forces. The struggle for the attainment of these two dichotomous goal hierarchies leads to the structure of the system components as discussed in the next sections.

The Attackers

The attacking force is composed of ICBMs carrying actual reentry vehicles, decoys designed to simulate reentry vehicles or deceive BMD radars, and chaff employed to screen the attacking force from enemy radars. The total system composed of all the ICBMs attacking target areas similar to the hypothetical target area can be decomposed into a single system made up of the RVs, decoys, and chaff carried on board a single ICBM without loss of meaningful detail due to the explicit assumption of homogeneity. Each of the four subsystems of this system will be described in light of their functional contributions to the attainment of the attacking force's goal hierarchy.

The ICBM. The United States had a successful test of its first ICBM, the Atlas, in the late 1950s (Ref 3:75). The first operational squadron was turned over to the Strategic Air Command in September of 1959. At the same time, the U.S. government conceded that the USSR had a similar operational capability (Ref 3:112). The deployed systems of the U.S. have evolved from those early ICBMs with single, large yield warheads to the newest version of the Minuteman III

ICBM that has three, relatively low yield but highly accurate RVs per ICBM. The range of strategic targeting options has also evolved, based on the capabilities of the deployed system. The ICBM of the near future is the MX. It is capable of carrying many RVs with yields and accuracies sufficient to qualify them as hard target killers.

<u>The Reentry Vehicles</u>. ICBM reentry vehicles can be characterized as belonging to two general categories: those which have relatively poor accuracy and large yield making them suitable for soft targets, and those which have excellent accuracy, low yield, and are suitable for use against hard targets. Of course, RVs from the second category can be used against soft targets though this may be inefficient from an optimal use of weapons standpoint. As a result, the ICBM capability can be said to be driving the strategy of their application. An example of this is the way in which the "mutual assured destruction" strategy of the 1960s gave way to the limited counterforce proposals of Secretary of Defense Schlesinger in the mid-1970s (Ref 19:3-4). This shift in U.S. strategic doctrine from targeting large cities (soft targets) to targeting enemy offensive forces (hard and soft targets) was possible because of the development and deployment of the second category of RV (Ref 19:5-6). The trend of RV research and development has continued to be in the direction of carrying multiple RVs of the second, or hard target killing, category. The Mk 12A reentry vehicle

which is deployed on some current ICBMs is a good example of this trend, as is the Advanced Ballistic Reentry Vehicle (ABRV) that may be deployed in the future (Ref 8; 23). A reentry vehicle currently under development may offer promise as the ultimate in ICBM-delivered, hard target killers. This new RV is the Advanced Maneuvering Reentry Vehicle, or more simply, AMARV.

There are two capabilities that make the AMARV different from other RVs. The first is indicated by its name, that is, a maneuvering capability after the RV separates from the post-boost vehicle. Unlike other RVs that fall ballistically to the target, the AMARV, with the use of a digital computer on board the RV, can perform a series of controlled maneuvers on the way to the target area. This has two purposes. The first is to make it harder for enemy defenses to destroy the AMARV. The problem the BMD must solve is predicting where an attacking RV is going and then launching a missile to intercept an RV attacking a target that must be defended. The maneuvering of the AMARV makes both the trajectory prediction and actual interception much more difficult. This type of AMARV, termed an <u>evader</u>, compares the position of the AMARV to the prestored target coordinates and maneuvers to the coordinates. The other purpose of the ability to maneuver is to support the second capability of the AMARV that makes it different from the other RVs, terminal guidance (Ref 1:43-45; 4).

The AMARV can theoretically be deployed with a target recognition capability. This differs from using prestored target coordinates. Together with the ability to maneuver, the terminally guided version of the AMARV can theoretically be steered with almost perfect accuracy through the defenses to the target. Both versions of the AMARV, and other RVs, are designed to be used in conjunction with penetration aids, such as chaff and decoys.

Chaff and Decoys. Chaff and decoys are designed to aid the penetration of actual RVs through the defenses to the target area. Chaff is deployed in long, roughly cylindrical tubes. The RVs and decoys are positioned inside these tubes and are screened from the BMD radars by the chaff. The RVs and decoys travel much faster than the falling chaff and, therefore, separate from the chaff screen. After this separation, another means of deception is used.

One type of decoy, designed to present the same observable characteristics as actual RVs such as radar cross section and wake, is used to prevent the BMD radars from correctly identifying threats. This type of decoy is called a precision decoy. Traffic decoys are smaller and are deployed in large numbers in an attempt to overload the BMD tracking and data handling systems (Ref 7:40). Thus, chaff and decoys are deployed to aid penetration by first screening and then disguising the actual RVs.

The Defenders

Ballistic missile defense falls into three basic categories, boost phase defense, midcourse defense, and terminal defense. Some proponents of boost phase defense envision a satellite-based, directed energy weapon that destroys the ICBM in the period immediately after takeoff while it is "large, slow, and soft," and before multiple RVs and penetration aids can be deployed (Ref 7:43). Boost phase defense technology will probably not be available in this decade but could become the BMD of the 1990s (Ref 7:43-44). Of more near term interest is midcourse defense, that is, defense that takes place after boost and before atmospheric reentry.

The advocates of midcourse defense call for the use of an optically guided interceptor that could use nonnuclear munitions as a kill mechanism. The BMD program is approaching the threshold of breaking the technology barrier of midcourse defense according to some, but deployable, operational systems are still many years in the future (Ref 7:41-43).

Historically, the third type, terminal defense, has received the most emphasis because the technology was most easily attainable. Terminal defense takes place in the atmosphere which favors the defense. The atmosphere slows down attacking RVs, filters out the chaff and other penetration aids, and provides RV wake observables that aid in threat identification and discrimination (Ref 7:38). All deployed BMD systems are of this type and all near future systems (1980s) will probably be of this type (Ref 7:42-43). As a result, this thesis only considers terminal BMD systems. Terminal systems are composed of the command and control facilities, such as the radars and computers, and the interceptors.

The Command and Control Facilities. The computers and radars of a terminal defense network must be extremely capable because of the compressed time frame of the engagement. The computers must be capable of performing tens of millions of instructions per second and handling probably the most demanding data processing requirement of any weapon system (Ref 7:38). There are typically about fifteen seconds for the system to track, identify, launch an interceptor, and have time for the interceptor to climb to the engagement (Ref 7:38). This leads to the defense's use of large, electronically steered, phased array radars and extremely high speed computers that are capable of handling hundreds of targets at once. The BMD critic's contention that these are targets that will be destroyed first, thus eliminating the defense, can be negated by the concept of mobility that is being stressed in some current and future BMD designs. The defense can be mounted on vehicles that will prevent them from being easily targetable. The purpose of the command and control facilities is to acquire the targets, identify the threats correctly, and launch interceptors.

The Interceptors. The interceptors for a terminal BMD are of two varieties, high altitude and low altitude. The high altitude or endo-loiter interceptor is launched when the threat cloud, made up of chaff, RVs, and decoys, is initially detected, long before individual threats are identified. The endo-interceptor climbs to the area where the radar will be able to correctly identify a reentry vehicle and waits for that identification to take place. It is then directed to the identified RV and detonated. Endo-interceptors use relatively high yield weapons (megaton range) and the primary kill mechanism is X-ray radiation throughout most of the EI region because the intercepts take place at high altitudes where air is not dense. The X-rays can kill RVs in a variety of ways such as damaging the RV heat shield causing the RV to either burn up on reentry or become aerodynamically unstable. The same radiations that are used to destroy attacking RVs can indirectly hinder the efforts of the defenders through a phenomenon known as blackout.

Radar blackout can be caused by the detonation of the ABM warhead. That much is certain. The problem is compounded, however, by other uncertainties. There is no clear analytic approach to the problem and the bans on atmospheric testing preclude experimentation. As a result, no one knows exactly what the effects are or how much degradation the BMD system effectiveness will suffer. Any effects will be magnified because of the large yield weapons used in the endo-intercept region (Ref 4).

The low altitude or point interceptor uses a smaller weapon (several kiloton range) and is launched to destroy any RVs that evade the endo-interceptors or after the inventory of endo-interceptors has been exhausted. Because X-rays are more readily attenuated by the denser atmosphere of the terminal region than neutrons, the primary kill mechanism in the point intercept region is neutron radiation. Neutrons destroy RVs by causing damage to the internal electronic equipment or to the RV warhead itself. Those reentry vehicles that evade the defense continue to the target area.

The Target Area

The hypothetical target area for this thesis is assumed to be made up of targets requiring several thousands of pounds per square inch (psi) of overpressure to be destroyed, or so-called hard targets. A good example of this kind of target area is an ICBM squadron with its command and control facilities and ICBMs in hardened silos.

Summary

The system under observation is composed of the attacking RVs, with the associated chaff and decoys; the defending BMD system, made up of endo-interceptors and point interceptors; and the target area. Because the actions of any system are very often different than the sum of the actions of the parts, nothing is gained by studying only the parts. The interrelationships between the parts must also be studied. This study can be accomplished with a simulation model. The model discussed in the next chapter will be used to analyze both the interactions of the system components and the components themselves.

III The Model

Introduction

This chapter presents the translation process from the actual system discussed earlier to the simulation model of the system. The development of the model follows the system science paradigm of conceptualization, analysis and measurement, and computerization. In the conceptualization phase, the components of the system are identified and the first attempts at identifying their interrelationships are made. The central goal of this phase is a structural model of the system. To accomplish this, the attackers, defenders, and the target area are closely studied with the objective of gaining a complete understanding of how the actual system functions. This understanding of the system is vital for the second phase of model development, analysis and measurement.

The analysis and measurement phase begins the quantification of the model. The underlying mathematics and physics of the engagements between the attacking RVs and the endo-interceptors and point interceptors and the damage to the target area by penetrating RVs are presented. These form the parametric model of the system that is necessary for the third phase of the paradigm, computerization.

The objective of the computerization phase of model development is the combination of the structural and parametric models to form a computer simulation model of the actual system. The discussion of the computerization phase includes the main program and supporting subroutines. The detailed and annotated codes are contained in Appendix C.

The final phase of the model development is the verification and validation of the model. The last section of this chapter details the efforts designed to ensure that the model behaves as intended and reflects a realistic view of the real system.

Conceptualization

The conceptualization phase of model development begins with the definition of the goals of the simulation. These are outlined in the first chapter of this thesis. The major objective is to provide a model that permits analysis in all areas of the engagements between the attacking RVs and the deferding ABM system. In order to accomplish this, the actual system must be studied and the components and functional relationships identified. The three major components and their capabilities are defined as precisely as possible so that they can be modeled. The next sections detail the thesis definitions of and assumptions concerning the major components.

The Attackers. The three subsystems that comprise the attacking force are the ICBMs, the RVs, and the penetration aids (chaff and decoys). The overall battle can be modeled on the level of one ICBM and its load of RVs and penetration aids versus one BMD system. The hypothetical

ICBM of this thesis can carry up to 4000 pounds of RVs and penetration aids. It is a solid fuel ICBM and has a range with the defined mission weight comparable to the newest U.S. systems(Ref 26). This thesis does not model the launch of the ICBM. Such issues as prelaunch survivability and launch reliability are not addressed. Rather, the simulation begins as the post-boost vehicle has reached the point at reentry when the RVs and aids will be deployed. The post-boost vehicle deploys the RVs, one by one, with some time between separation of each RV. This time between RV deployments is affected by factors such as the desired spacing between objects in a chaff cloud, and the ground distance between targets.

The RVs that can be carried by the hypothetical booster can range from RVs such as are presently deployed on Minuteman III, to those planned for deployment on a future MX ICBM, to theoretical, as yet untested RVs. For demonstration purposes in the model, this thesis uses two different types, a maneuvering RV (MRV) and a nonmaneuvering, or ballistic RV (BRV). The assumed capabilities are displayed in Table I.

TABLE I

Model Reentry Vehicle Performance Characteristics

RV Type	Yield(kt)	CEP(feet)	Weight(lbs)
MRV	150	200-600	350
BRV	350	600	350

The values in Table I are assumed for demonstration purposes only and do not reflect the performance characteristics for any actual weapon system. The values can be changed with little difficulty to allow the analysis of an actual system. A demonstration of the ease of changing parameters is found in the example experiment found in Chapter IV.

Both of these hypothetical RVs are assumed to be protected against nuclear effects from interceptor weapon detonations to some designed vulnerability levels. These levels are changeable in the model. The RVs are electrically compatible and similar in size so that they can be placed at any RV station in the post-boost vehicle. This means that the two types are interchangeable but the maximum total number of RVs that can be carried at one time is ten, regardless of whether or not penetration aids are deployed.

Although the actual deployment of penetration aids is not simulated in the model, their use is an implicit assumption. This assumption results in the 150,000 feet altitude that represents the level at which individual RVs are correctly identified by the ABM radars. Without the use of penetration aids, the discrimination altitude would be much higher, resulting in a much larger engagement regime. The consideration of either traffic decoys designed to overload BMD command and control subsystems or decoys designed to give the same observable characteristics as actual RVs is also reflected in the probabilities of correct discrimination in the model networks for the EI and point defenses. The use of electronic countermeasure (ECM) decoys designed to jam or deceive BMD radars can also be modeled by reflecting the impact of their use on the probability of correctly discriminating the threats by the BMD.

Just as the attacking forces can be represented by the subsystems of a single ICBM and its load of RVs and penetration aids, the defenders can be represented by a single system made up of command and control, endo-interceptor and point interceptor subsystems.

The Defenders. The performance of the command and control subsystem of the BMD is modeled in terms of its capability to correctly discriminate and engage the threat. This performance forms a part of the probabilities of discrimination used in the model network to route entities to engagements if discriminated correctly or to bypass the engagement simulation if not correctly discriminated. However, the probabilities of discrimination figures reflect an aggregation of many more probabilities. For example, the launch reliabilities of the interceptors are included as well as the probabilities of weapon fusing and detonation. As a result, the probabilities of discrimination assessed for the BMD system are critical and the sensitivity of the system to these values is analyzed. However, the actual calculation of these figures is outside the scope of this thesis. This same type of simplifying assumption is used in the simulations of the engagements between the interceptors and the attacking reentry vehicles.

The underlying aerodynamic performance of the interceptors is not modeled. The concept of weapon radius (WR) is used in the simulation of engagements. The mathematical derivation of the weapon radius is contained in Appendix B but, in general terms, the weapon radius is used to generate the probabilities of kill in the engagements. The weapon radius, of course, varies based on the specific interceptor, endo-interceptor or point interceptor.

The hypothetical endo-interceptor is assumed to have some form of loiter capability. It is launched well in advance of actual target discrimination and climbs to the upper level of the endo-intercept region. Once the final discrimination has taken place, the endo-interceptor is directed to the engagement with the attacking threat. Since this engagement takes place in atmospheric regions of low air density, the powered maneuvering of the endo-interceptor can partially negate the aerodynamic maneuvering of the MRV. Rather than model the intricate maneuvering process engendered by the engagement process, the model uses the weapon radius concept. The weapon radius is affected by a variety of factors that are illustrated in Appendix B. The warhead on the interceptor is a large yield, thermonuclear device in the megaton range. The intent of the use of this large warhead is to overcome the disadvantages of the interceptor in the endo-intercept engagement. One of these disadvantages is the classical one of the defense being forced to react to the initiative of the attacker. Since the attacker is still far above the target, an attacking maneuvering RV can perform violent maneuvers in the endo-intercept region and still have enough time to maneuver to the target. This is less true in the point intercept region.

The interceptor in the point intercept region is assumed to be a small, high acceleration, extremely maneuverable, solid fuel missile with a warhead in the several kiloton range. This smaller weapon is needed partly because of less time to maneuver for an attacking RV and partly to prevent collateral damage from the detonation of the ABM. A related issue to this collateral damage problem is the potential for ABM radar blackout as a result of weapon detonation. This is not modeled in this thesis because no concrete information dealing with the blackout potential could be found.

In addition to the assumed capabilities of the hypothetical interceptors, the strategy of the defense is assumed to be to engage each RV with one ABM at a time. This means there is no netting, or engaging a single RV with two or more interceptors from a single zone (endo or point). However, a reentry vehicle that successfully penetrates the endo-intercept zone can be engaged by a point interceptor. An additional assumption is that an interceptor can only damage the specific RV it is engaging; collateral damage of a RV other than the one targeted is not modeled.

The Target Area. The target area used in this model is made up of fixed, homogeneous, hard targets. The model contains the explicit assumption that these targets are spaced so that each individual target can only be damaged by the specific RV attacking it. That is, one RV missing its target cannot damage another target. An example of this type of target area is an ICBM squadron.

The FORTRAN subroutines that calculate the level of damage suffered by each target only consider overpressure. There are two reasons for this. The first is ease of calculation. Although ICBM silos, for example, are susceptible to damage caused by ground shock, the calculation of the level of damage caused by ground shock is an imprecise science at best. The second reason for only considering overpressure effects is that damage caused by these effects can be visually confirmed by reconnaissance after the attack.

Another assumption in the model is that each target is attacked by only one RV. There is no N-on-one strategy which would have two or more RVs attacking a single target. The three major components discussed previously, the attackers, the defenders, and the target area, form the basis for the structural model of the system.

The Structural Model. The development of a structural model of the system being studied is vital in order to gain a fuller understanding. The three components already identified, the attackers, the defenders, and the target area,

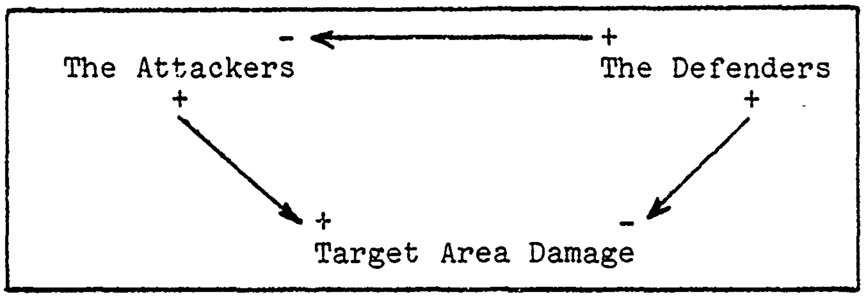

Fig 5. Basic Causal Loop Diagram

can be used to develop a basic causal loop diagram, the beginning of structural model development.

The intent of Figure 5 is to visually demonstrate the interactions between components. For example, the arrow between the defenders and the target area indicates that a large number of defenders should result in a negative effect on the target area component as measured by the target damage level, that is, less damage. Similarly, an increase in the number of attackers should result in a positive effect or more target area damage. This simplified view of the system can be made more complex with an introduction of some of the parameters involved. Table II is a partial listing of the system parameters.

Although these parameters do complicate the issue, the actual structure of the system is still relatively straightforward. The underlying structure, or logic flow, of the system is illustrated in Figure 6. The figure uses the four parts of the system as described by Matlin, the weapon complex, the target complex, the engagement model, and the damage model (Ref 12:337).

TABLE II

The Missile Allocation Problem: A Partial Parameter Listing (Ref 12:335)

ATTACKER

Booster Characteristics (for each weapon type)	
Location	Availability
Range	Survivability
Accuracy	Reliability
Memory	Bomb damage assessment
Penetration aid mix and effectiveness	Etc.
RV Characteristics	
Accuracy	Signature
Yield	Indirect bomb damage assessment
Δ range, Δ crossrange capability	Survivability
	Etc.
Command and control	
Target sharing	Redundancy and survivability
Reprogramming	Reaction time
Weapon commitment	Etc.

OBJECTIVES

Offense
- Damage criterion per target
- Total criteria

Defense
- Damage criterion per target
- Over-all criteria

INTELLIGENCE

What the defense knows about the offense
- Number of attacking missiles
- Number of salvos
- Salvo composition
- Missile payload mix
- Etc.

What the offense knows about the defense
- Terminal ABM inventories, distribution among targets
- Area ABM inventories
- Preferential defense strategy
- Etc.

TABLE II - Continued

DEFENDER

Target complex
  Locations/uncertainties
  Configurations
  Values
  Hardness

Defenses
  Terminal inventories
  Terminal effectiveness
  Area coverages
  Area characteristics (inventory, choice, effectiveness)
  Radar capabilities (tracking, impact prediction, capability)
  Civilian defense program

SCENARIO (strategic environment)

Enemy first strike
  Assured destruction mission for U.S.
  U.S. attrition

U.S. first strike
  Damage limiting mission for U.S.
  (Counterforce, countervalue, retained)
    mix

Selective threat targeting philosophy

Progressive confrontation (tit-for-tat) targeting

Collateral damage restrictions

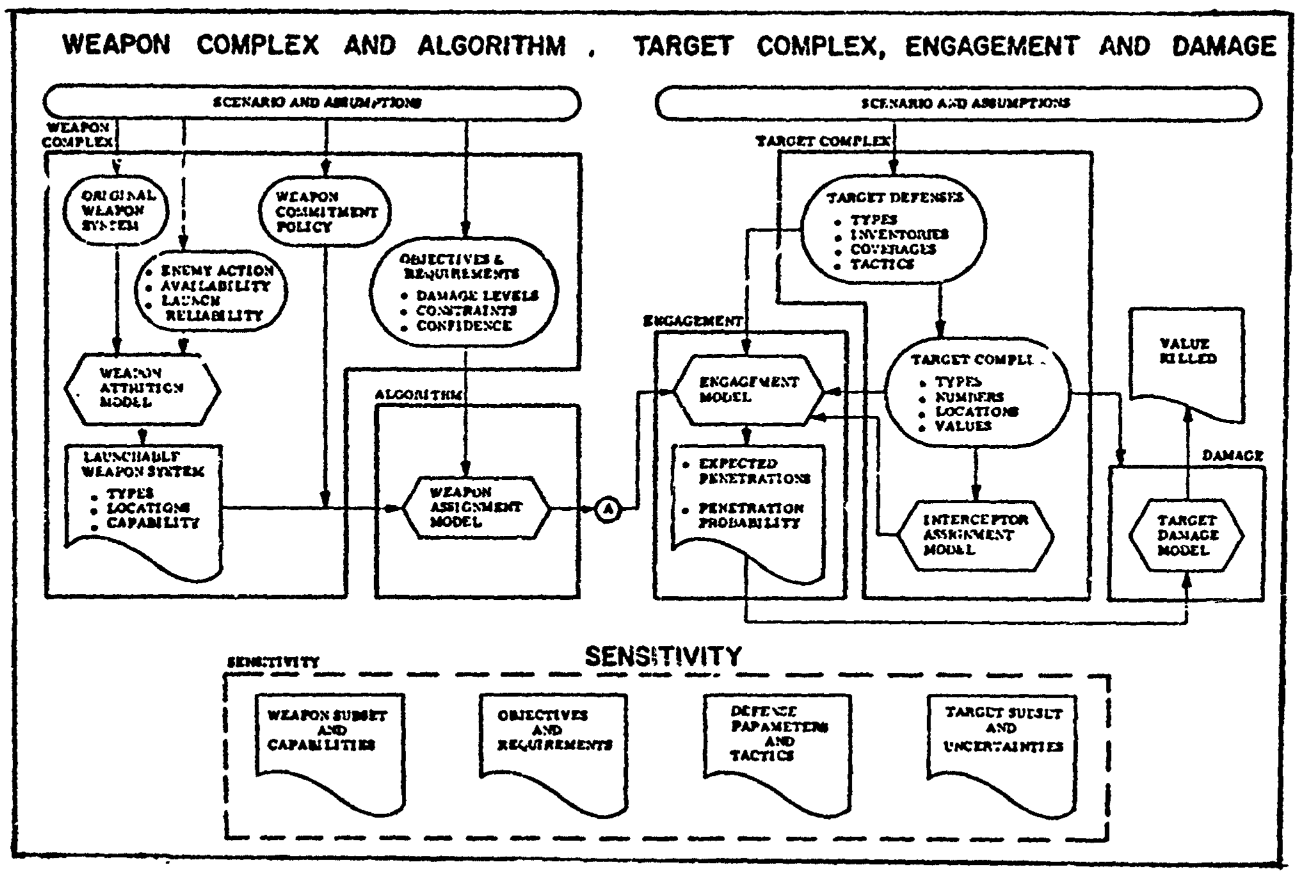

Fig 6. Underlying Logic Flows (Ref 12:336)

Using the aforementioned list of system parameters and the underlying logic flow of Matlin, the basic causal loop diagram can be expanded. Combining the knowledge of the system components and their interactions gained from the basic causal loop diagram, the list of system parameters, and Matlin's underlying logic flow yields the structural model of the system. This is depicted in Figure 7.

An integral part of the structural model is an identification of the system variables by type. The control variables, stochastic variables, and response variables must be identified. This identification is depicted in Table III. The control variables are those input variables over which the decision maker has control. This control may exist through policy decisions such as equipment design and development decisions, and/or employment decisions. Depending upon the purpose for which the model is used, the decision maker may have to rely on intelligence and technological estimates to control these variables. Stochastic variables are those input variables over which the decision maker has no control. The values of these variables are probabilistic. The response variable is the output variable that is used to measure the effectiveness of a component or the system.

The structural model illustrates the framework of the system. The components of the system are apparent, as are their interrelationships. In order to measure these interactions, however, the model must be quantified. Some numerical relationships must be developed. These mathematical

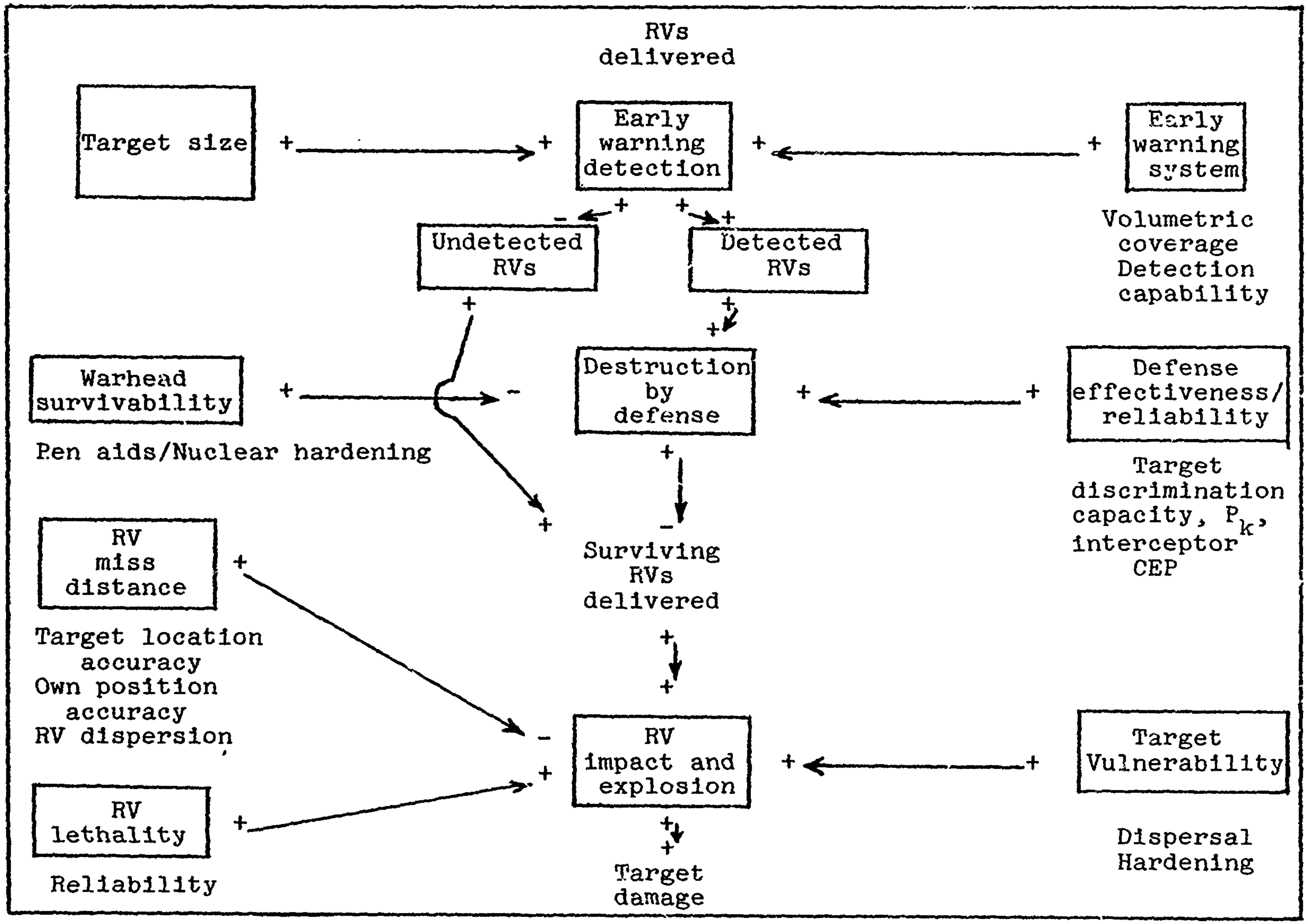

Fig 7. Structural Model (Ref 18:109)

TABLE III

Variable List by Type

ATTACKER:

CONTROL VARIABLES	STOCHASTIC VARIABLES	RESPONSE VARIABLE
RV mix	RV drop off rate	RVs on target
Yield	Miss distance	
RV vulnerability levels		
RV reentry angle		
RV speed		
Time for RV to fly thru defenses		
Targeting strategy		
CEP		

DEFENDER:

CONTROL VARIABLES	STOCHASTIC VARIABLES	RESPONSE VARIABLE
Type	Intercept altitude	RVs destroyed
Location/configuration	Discrimination/ detection capability	
Numbers of ABMs	Miss distance	
Warhead yield		
Warhead type		
Minimum reaction time		
Targeting strategy		
CEP		

TARGET AREA:

CONTROL VARIABLES	STOCHASTIC VARIABLES	RESPONSE VARIABLE
Value		Target area destruction
Hardness		
Location		
Size		

relationships form a parametric model, the central goal of the next phase of model development, analysis and measurement.

Analysis and Measurement

The understanding of the system developed in the conceptualization phase of system analysis is vital for the development of the parametric model that is the objective of this phase.

The Parametric Model. The mathematical relationships of interest fall in four areas: (1) the time/velocity functions for RV reentry, (2) the X-ray and neutron calculations, (3) the weapon radius (WR) calculations used to determine probabilities of RV kill by the defense, and (4) the target damage level calculations. The last three are contained in Appendices A and B. There are several assumptions central to the development of the parametric model. These are made explicit as they are needed. Figure 8 is used to develop the time/velocity functions for RV reentry. If a straight line RV trajectory is assumed, that is no maneuvering, then X represents the RV reentry angle. Since,

$$\sin(X) = \frac{\text{vertical distance through EI zone}}{\text{slant distance traversed by RV through EI zone}} \qquad (1)$$

then,

$$\text{the slant distance traveled by the RV through the EI zone} = \frac{80{,}000}{\sin(X)} \qquad (2)$$

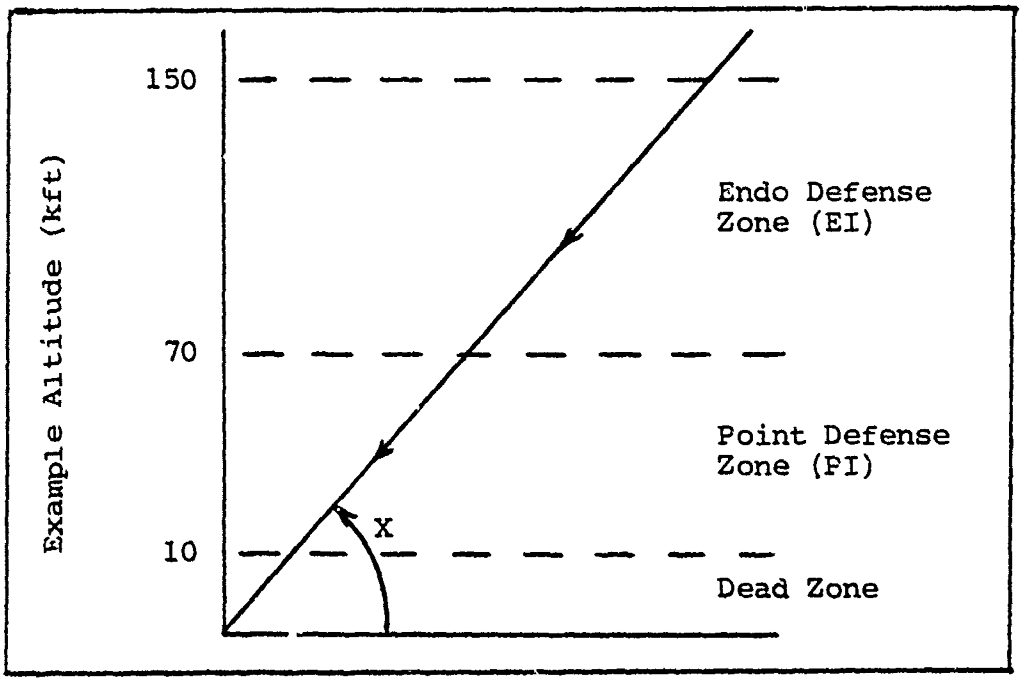

Fig 8. Sample RV Trajectory

This assumes, of course, that there are exact upper and lower boundaries for the EI zone. The same assumption applies for the PI zone and, as a result,

$$\text{the slant distance traveled by the RV through the PI zone} = \frac{60{,}000}{\sin(X)} \tag{3}$$

Eqs (2) and (3) lead to the calculation of time spent in each region with the assumption of constant velocity, V.

$$\text{Time to traverse EI zone} = \frac{\text{Slant Distance}}{V} \tag{4}$$

$$\text{Time to traverse PI zone} = \frac{\text{Slant Distance}}{V} \tag{5}$$

The absolute minimum time that can elapse between the time a reentry vehicle enters a zone and is engaged is the minimum reaction time of the interceptor. The maximum time from entry to engagement is the total time spent in the zone. Since the hypothetical ABM system of this model is not an actual system, no data exist on the probability distribution function that describes the distribution of intercepts within a zone. Although the natural tactic of the defense would be to engage as high in each zone as possible, thereby maximizing the lethal radius because of lower air density, the defense must react to the offense. This means, for example, that in the EI zone, the ABM must accelerate and then maneuver to engage the RV. As a result, relatively few engagements should occur at the upper boundary. Since the RVs are capable of much higher velocities than the ABMs, relatively few engagements should occur at the lower boundary as well because this implies a tail-chase not winnable by the interceptor. The set of candidate probability distribution functions to describe the distribution of intercept altitudes throughout each region is large. It includes a triangular form; a lognormal; a normal, either symmetric or skewed; or a beta probability distribution function, to name just a few. Historical data are scarce because of the short history of deployed BMD systems. Therefore, analysis of the results of specific intercept distributions was required. A test was designed using the weapon system capabilities and vulnerabilities for both the offense and defense as contained in the example simulation in Appendix C. That is, the vulnerabilities of the attacking RV to X-ray and neutron fluence were set at the same levels as the hypothetical Maneuvering RV (MRV). These were 70 cal/cm^2 and 100 cal/cm^2 for X-ray sure safe and sure kill levels, respectively, and 1 x 10^{13} neutrons/cm^2 and 1 x 10^{15} neutrons/cm^2, for neutron fluence. The two hypothetical interceptors had yields of one megaton for the endo-interceptor and twenty kilotons for the point interceptor. The CEP for the endo-interceptor was 3000 feet; the CEP for the point interceptor was 1000 feet.

The test consisted of forty engagements between a RV and an interceptor, twenty in the EI region and twenty in the PI region. The RV was assumed to be correctly discriminated. A triangular function was used to distribute the intercept altitudes with the most likely altitude set at a point most disadvantageous to the defense. Because of atmospheric attenuation, the lethal radii of both primary kill mechanisms, X-ray and neutron fluence, shrink as altitude decreases and the density of the atmosphere increases. Therefore, the most disadvantageous altitudes for the defense are the lowest in each zone. Even with the defense at this disadvantage, all forty engagements resulted in the RV being killed.

As a result of this test, and other preliminary analysis, a normal probability distribution function was assumed for the distribution of intercept altitudes in each zone. The normal form is assumed to have the following parameters.

The mean,

$$\mu = \frac{\text{(time to fly zone - ABM minimum reaction time)}}{2} \quad (6)$$

and standard deviation,

$$\sigma = \frac{\mu}{3} \quad (7)$$

The probability distribution function can be changed within the model to reflect differences in BMD systems. Other functional forms can be substituted if desired.

Eq (8) follows from Eqs (1) - (5).

$$\text{Time to fly Dead Zone} = \frac{10{,}000}{\sin(X)} \quad (8)$$

As a result of the calculation of the time of intercept in each zone, the intercept altitudes can be determined. The results of Eqs (9) and (10) are needed to determine radiation levels and probabilities of kill.

$$\text{EI altitude} = 150{,}000 - \text{(intercept time)}(v)(\sin(x)) \quad (9)$$

$$\text{PI altitude} = 70{,}000 - \text{(intercept time)}(v)(\sin(x)) \quad (10)$$

Computerization

The objective of the third phase of system analysis, computerization, is a computer model of the system. The structural model developed during the conceptualization phase can be changed into a structural model more suitable for computerization by adopting a network orientation. By this, it is meant that each RV must follow a certain path from the drop-off point from the post-boost vehicle, through the endo-intercept and point intercept regions and the dead zone, to the target area. Along the path are decision points, or nodes, where decisions must be made as to whether or not the RV will continue. For example, in the endo-intercept region, the RV may be engaged by the interceptor. This engagement can be represented by a node in a network where the decision is made on the success of the engagement. Figure 9 represents the computer logic of this network.

The Simulation and Modeling Language (SLAM) was chosen for the main program because of its amenability to programming network structures. It provides a structural model of the system, laid out as a network, and permits the very real advantage of control over this structural model during the simulation. This means that not only can parameters such as weapon yields and accuracies be altered, but the physical structure of the system can be changed, all without interrupting the operation of the model. The reason for this tremendous flexibility is the SLAM global variable. Although more detail is presented in Appendix C, briefly, global variables can be used to open and close network paths, activate and deactivate defenses, or redefine weapon system capabilities and vulnerabilities, while continuing the simulation. The use of this special purpose language, and the resulting flexibility in the simulation of a critically important

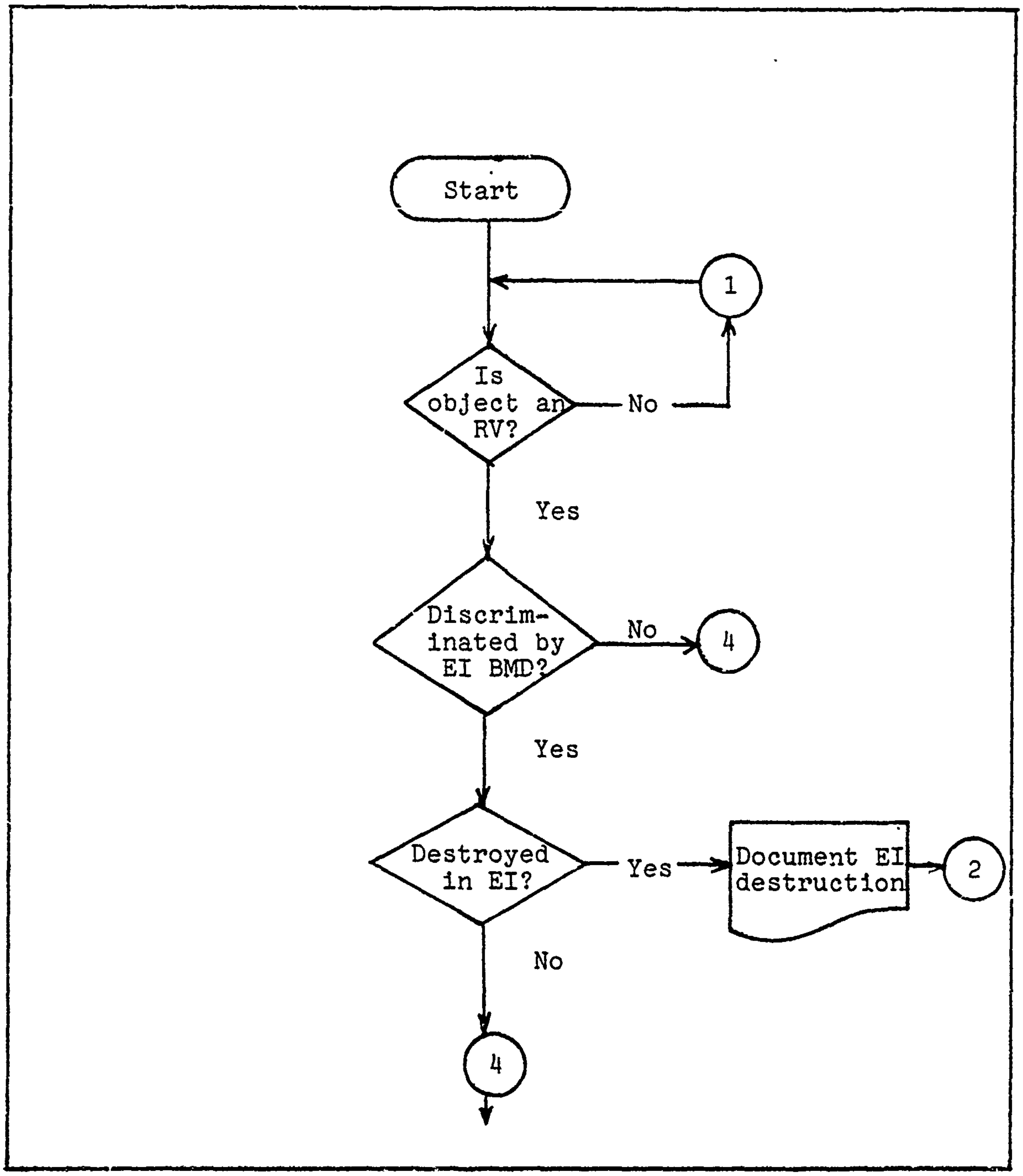

Fig 9. Computer Model Flowchart

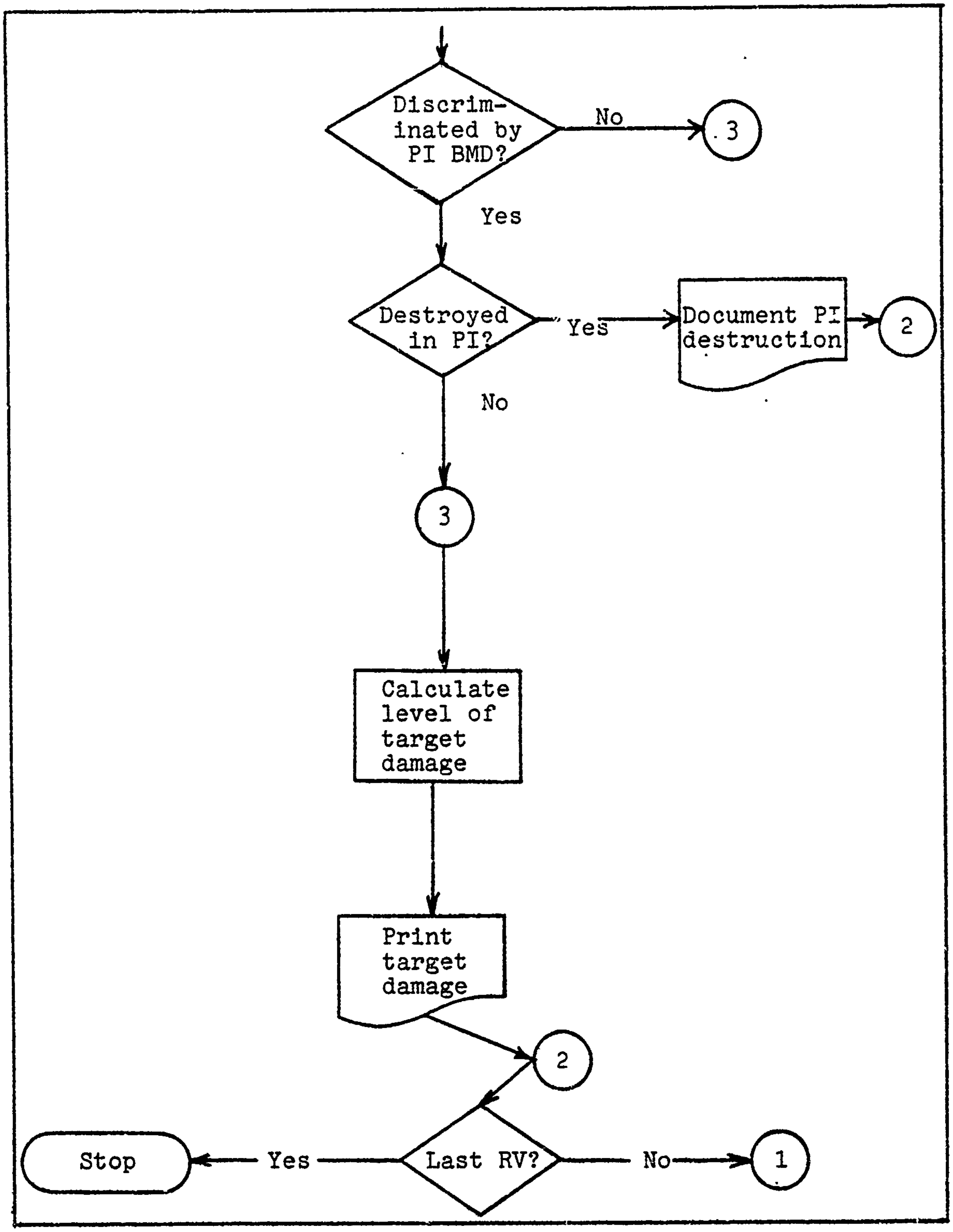

Fig 9. - Continued

subject area, is the key to the value of this RV/ABM engagement model.

The language of the subroutines that support the SLAM main program is FORTRAN V. These subroutines are the computerization of the parametric models developed in the analysis and measurement phase. They provide RV reentry time and velocity information, as well as the results of the RV/ABM engagement simulations and target damage levels. Annotated listings and detailed explanations of the main and supporting programs are contained in Appendix C.

The end result of the computerization phase is a computer model that combines the structural model of the conceptualization phase and the parametric model developed in the analysis and measurement phase. The model contained in this thesis allows detailed analysis of the system and identification of statistically critical components, interactions, and parameters. But the mere development of a simulation model is not enough. The model must be verified and validated before use as an analytical tool.

Verification and Validation

Verification is the process of ensuring that the parts of the model and the entire model, itself, operate as intended by the designers. Validation, on the other hand, is ensuring that the model is an accurate representation of the actual system. Both processes must be accomplished if the model is to be used to analyze the real system.

The Verification. The verification process for this model was conducted in two stages, one for the main program and one for the supporting user functions (subroutines). The verification of the main network was accomplished with a building block approach. Each part of the model was run alone with the SLAM TRACE option to make sure that the model part was behaving as intended. By this, it is meant that each entity flowed through the network, gained attribute values where and when intended, and followed the designed path. Figure 10 is an example of the verification of the first block in the network. With the TRACE option activated, all entities (RVs) could be tracked through the Arriving RVs block of the model. Attributes 3 through 6, assigned by subroutines, could be verified, and the designers of the model could ensure that the block was operating as intended. After the first block had been verified, the second, or Endo Defense, block could be verified separately and then added to the first block and verified jointly. This process continued until each block had been separately verified and the main program had been verified as a whole.

The second stage of the verification process involved the supporting FORTRAN code. These subroutines supply information to be used in the main program such as neutron and X-ray fluence, or radiation levels, and damage levels. Analytic, closed form solutions exist for these calculations and form the basis for the programming in the subroutines. The subroutines were run with test data and their outputs

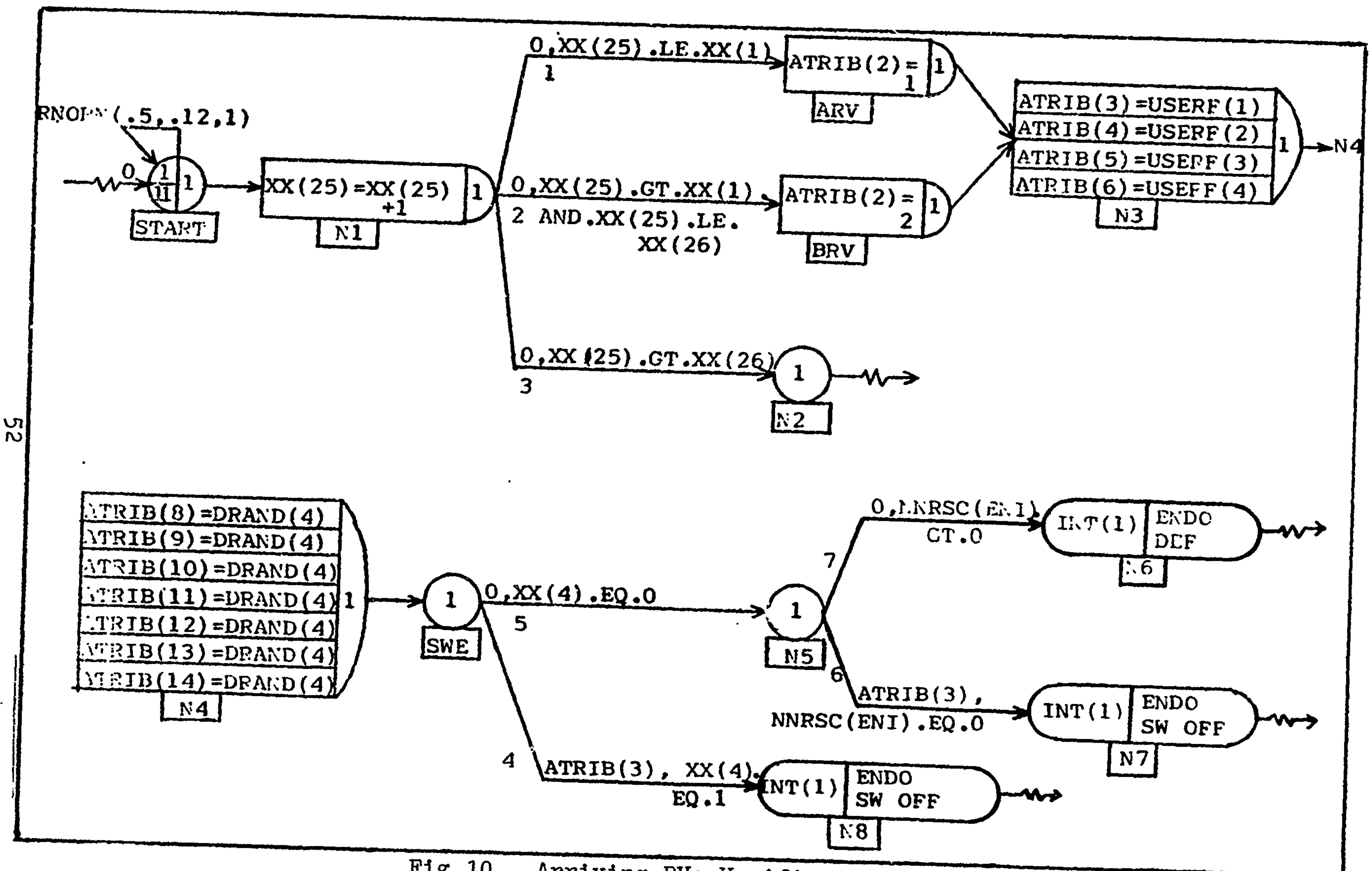

Fig 10. Arriving RVs Verification

compared with the results of the analytical solutions. An example of this is in Appendix D. The results of both methods agreed. The accuracy of the analytical solutions themselves, and the resulting subroutines, was further verified as a result of their examination by a recognized expert in the field of nuclear weapons effects, Dr. Charles J. Bridgman of the Department of Nuclear Engineering, Air Force Institute of Technology. Dr. Bridgman is an expert in both the theoretical side of the weapons effects field and the operational side, weapons testing, as demonstrated by his academic credentials and his years of experience in the field, actually testing nuclear weapons. Dr. Bridgman's examination was invaluable not only in model verification but also in validation.

The Validation. The process of model validation, or ensuring the model accurately represents the actual system, was based on two definitions of what constitutes a valid model. The first, and more conventional, definition states that a model is valid if it accurately predicts the conditions of the actual system. Based on the verification process previously described, during which an expert confirmed that the output of the model agreed with the results reached by widely accepted, analytic solutions, the authors of this thesis believe that the model is valid as they have defined model validity in the first sense.

The second definition of model validity corresponds to the position espoused by Naylor, et. al., in Computer Simulation Techniques, when validating policy models. They feel that since the objective of a policy model is to recommend a specific course of action, or policy, the adoption of that policy by the decision-making authority validates the model (Ref 16:315). Put more simply, if the objective of a model is analysis that results in change, and change results, the model is valid. A related position may be offered. If the objective of a model is to provide a tool for analysis, and experts in the field are willing to use the tool (or model), then the model is valid. According to this empirical definition, the model in this thesis is valid. The assumptions, processes, programming, and methods used in this model were presented to USAF officers involved in both the fields of ABM intelligence analysis and ABM/RV system analysis. They concurred with the model and expressed interest in adopting it as an analysis technique for the Strategic Air Command (Ref 22).

Summary

This chapter has traced the development of the model through the three phases of the system science paradigm, that is, conceptualization, analysis and measurement, and computerization. It also detailed the efforts of the authors to both verify and validate the model. The next chapter, Chapter IV, contains an example problem designed to demonstrate the operation of the model and permits analysis of the model and the actual system.

IV Example Experiment

Introduction

In order to demonstrate the accomplishment of two of the thesis objectives and to further the validation effort, an example experiment is designed. The experiment also illustrates one prospective use of the model and partially demonstrates the flexibility offered by SLAM and the model design in analyzing the sensitivity of the response variable to changes in the control and stochastic variables. The question to be answered by the experiment is from the point of view of the attackers. However, this is not the only point of view for which the model can be exercised.

Due to the highly sensitive and classified nature of nuclear targeting parameters, proposed BMD system characteristics, and existing and proposed RV characteristics, the full flexibility of the model cannot be demonstrated in a thesis effort. The values of all variables and parameters in the example experiment are based on values obtained from unclassified papers, periodicals, studies, and conversations with experts in the field (Ref 1:43-45; 2:17; 4; 5; 8; 13:12-18; 14; 22; 23:7; 25:368; 26).

Experimental Design

The example experiment is designed to answer the following question:

> Assuming the presence of an improved BMD system composed of an upper layer, endo-atmospheric and lower layer, point defense systems, what is the best RV

load mix for a delivery vehicle to achieve the greatest probability of target destruction? The load will consist of new, maneuvering RVs and current RVs.

An intuitive screening of the control, stochastic, and response variables in Table III, and preliminary runs of the model during the verification phase, indicate that three variables should be regarded as being the most significant contributing factors in answering the above question. That is, the value of the response variable is most sensitive to the values of these three variables. These three variables are RV mix, CEP of the new RV, and the probability of the point defense discriminating a new RV. In a statistical experiment, these variables are referred to as factors. The response variable of interest is target area destruction. The resulting experimental design chosen for this experiment is a three-factor design, structured as follows:

$$y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkl} \quad (11)$$

where

μ	= mean
α_i, β_j, γ_k	= main effects
$(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$, $(\beta\gamma)_{jk}$	= two-factor interaction effects
$(\alpha\beta\gamma)_{ijk}$	= three-factor interaction effect
ε_{ijkl}	= error term

In such a factorial experiment, all levels of a given factor are combined with all levels of every other factor (Ref 15: 428; 21:164).

The levels of each factor are then chosen. Three levels of each factor are chosen to keep the number of levels and the resulting costs to a minimum, and to gain certain analytical advantages (Ref 21:154). The three RV mixes chosen are three new RVs and seven current RVs, five new RVs and five current RVs, and seven new RVs and three current RVs. To date, the exact values of the CEP of the new RV and the probability of the point defense discriminating a new RV are unknown and merely conjecture. The three CEPs chosen for the new RV are 200, 400, and 600 feet. A CEP of 200 feet is a goal in the design of the RV. A CEP of 600 feet is chosen since another design goal of the new RV is that the accuracy be at least as good as that of the current RVs. The CEP of 400 feet is chosen as a mean value. Three figures are chosen as the probability of the point defense discriminating a new RV. These are .5, .3, and .1. Preliminary runs of the model indicate that if the discrimination probability of the point defense is higher than .5, no difference exists between using new and current RVs. The three factors and three levels of each factor yield the functional form of the experiment depicted in Figure 11.

Such an experiment is symmetrical, all of the factors are set at the same number of levels. A complete experiment is desired. That is, one response measurement is desired in

		RV Mix 1			RV Mix 2			RV Mix 3		
Discrimination Probability		1	2	3	1	2	3	1	2	3
CEP of New RV	1									
	2									
	3									

Fig 11. Functional Form of the Experiment

each cell in Figure 11. This experimental structure is described by

$$N_s = q^k \qquad (12)$$

where

N_s = number of cells in the experiment

q = number of levels of each factor

k = number of factors in the experiment

In order to assess three-way interactions, two response measurements are desired in each cell. Eq (12) becomes

$$N = pq^k \qquad (13)$$

where

N = total number of computer runs required

p = number of response measurements in each cell

The definitions of q and k are as before. Substituting the appropriate values into Eq (13) yields

$$54 = 2 \times 3^3 \quad (14)$$

Thus, 54 simulation runs are required (Ref 21:155-156).

The data from the 54 simulation runs will be analyzed using the analysis of variance (ANOVA) routines from the Statistical Package for the Social Sciences (SPSS). The ANOVA routines will be used to determine if the damage means produced by the RV mixes differ significantly. If these means differ significantly, a Duncan's multiple-range test will be accomplished using SPSS. This test divides the three RV mix means into subgroups such that any two means in a subgroup do not differ significantly. This test should indicate which RV mix produces a significant improvement in the average probability of target area destruction, if any (Ref 15: 382).

The relative differences among the target area damages produced by each mix is of interest, as opposed to the absolute value of the target area damage produced by each mix. Kleijnen suggests that correlated sampling is the appropriate variance reduction technique to be used in this case. Correlated sampling involves a comparison of the mixes under the same conditions. In other words, the average target area damage produced by each mix is simulated using the same sequence of random numbers. Common random numbers mean that the average target area damages are statistically correlated. This technique implies that each stochastic input variable has its own sequence of random numbers. As each mix is simulated, input values are generated using the same initial values for the random number generators as in the previous mix. In addition, further synchronization is required to ensure that identical random numbers are used for each RV in each mix at the same decision point during the simulation run. This variance reduction technique is implemented to reduce the random error and increase the precision of the experiment (Ref 11:200-202; 21:203-204).

In order to implement this technique and ensure the synchronization of random numbers from run to run, separate random number streams were used for RV drop-off rate, the time for the RV to fly through the endo-atmospheric defense, the time for the RV to fly through the point defense, and the disposition of the RV in the endo-atmospheric, point, and target regions. The SLAM code accomplishes the following:

1. RV #n gets the n^{th} random number in streams 1, 2, and 3, and gets the n^{th} seven random numbers in stream 4 for the first observation in each cell.

2. RV #n gets the $(n^{th} + 10)^{th}$ random number in streams 1, 2, and 3, and gets the $(n^{th} + 10)^{th}$ seven random numbers in stream 4 for the second observation in each cell. The streams are then reinitialized to generate the next two observations in the next cell. Random number stream 1 generates arriving RVs. Stream 2 determines the time to fly through the endo-atmospheric zone. Stream 3 determines the time to fly through the point zone. The first number in the

seven from stream 4 determines the miss distance of the endo-atmospheric interceptor, the second determines the discrimination probability of the endo-atmospheric interceptor, the third determines whether or not the endo-atmospheric interceptor destroys the RV, the fourth determines the miss distance of the point interceptor, the fifth determines the discrimination probability of the point interceptor, the sixth determines whether or not the point interceptor kills the RV, and the seventh determines the miss distance of the RV.

The attackers are assumed to be ten RVs contained on a single ICBM. The assumed strategy of the attackers is to send the new RVs through first in order to draw as many ABMs as possible and still retain a good defense penetration probability. The RV drop-off rate is assumed to be normally distributed with a mean of .5 and a standard deviation of .12 seconds. The assumed values of the new and current RV parameters are as indicated in Table IV.

The assumed capabilities of the defenders are depicted in Table V. Both defenses are activated. The temperature of the X-rays from the endo-interceptor's weapon is assumed to be eight thousand electron volts. In addition, the ratio of the number of interceptors to the number of RVs is assumed to be 1.5 to 1.

The assumed target area consists of ten hard targets, each protected by one point interceptor. The sure safe and sure kill vulnerability levels for each target are assumed

TABLE IV

Example Problem RV Capabilities and Vulnerabilities

			X-ray (cal/cm²)		
	Yield (kt)	CEP (ft)	Sure-Safe	Sure-Kill	Reentry Angle
New RV (ARV)	150	200	70	100	24°
Current RV (BRV)	350	600	20	50	24°

	Neutron (neut./cm²)		
	Sure-Safe	Sure-Kill	Velocity (ft/sec)
New RV (ARV)	1×10^{13}	1×10^{15}	22000
Current RV (BRV)	1×10^{12}	1×10^{14}	22000

TABLE V

Example Problem Defense Parameters

	Yield (kt)	CEP (ft)	Number Available	Probabilities of Discrimination	
				ARV	BRV
Endo-interceptor	1000	3000	5	.7	.7
Terminal Interceptor	20	1000	10	.5	.7

to be 2000 pounds per square inch (psi) and 6000 psi, respectively.

Table VI reflects the data generated by the experiment. The data was obtained by accomplishing three sets of simulation runs, obtaining 18 observations from each set. The SLAM code in Appendix C was used to obtain the 18 observations in the first row of Table VI. The SLAM code in Table VII supplements the code in Appendix C for this experiment. It should be noted that the code in Appendix C has the number of new RVs set to three and the point discrimination probability set to .5. To obtain the data in rows two and three of Table VI, the CEP of the new RV [XX(22)] in the basic code is changed first to 400 and then to 600.

Experiment Results and Conclusions

The results of a three-way ANOVA are presented in Table VIII. These results indicate that, at the 95% confidence level, CEP is not a significant main effect. That is to say that the target area damage is not sensitive to the new RV CEP. At this same level, none of the two-way or three-way interactions are significant. The ANOVA also indicates that there is a significant difference in the average probability of target area destruction produced by each mix.

Based on the lack of significance of the three-way interactions, the three-way ANOVA was again accomplished, forcing the three-way interactions into the error term. This was accomplished to determine if the two-way interactions

TABLE VI

Experiment Data Results

	MIX (ARV/BRV)								
	3/7			5/5			7/3		
DISCRIMINATION PROBABILITY	.5	.3	.1	.5	.3	.1	.5	.3	.1
200	0 .04041	0 .04041	0 .1404	0 .04041	0 .04041	0 .2404	0 .04041	.10 .04041	.20 .3404
400	0 .04041	0 .04041	0 .1311	0 .04041	0 .04041	0 .231	0 .04041	.10 .04041	.1175 .331
600	0 .04041	0 .04041	0 .04045	0 .04041	0 .04041	0 .05037	0 .04041	.09984 .04041	.09984 .06572

TABLE VII

SLAM Supplementary Code

```
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   INITIALIZE SEEDS, 2 RUNS
SIMULATE;
SIMULATE;                                REINITIALIZE SEEDS, SET DISCRIMINATION
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   PROBABILITY TO .3, 2 RUNS
INTLC,XX(11)=.3;
SIMULATE;
SIMULATE;                                REINITIALIZE SEEDS,SET DISCRIMINATION
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   PROBABILITY TO .1, 2 RUNS
INTLC,XX(11)=.1;
SIMULATE;
SIMULATE;                                SET NUMBER OF ARVS TO 5, SET
INTLC,XX(1)=5,XX(11)=.5;                 DISCRIMINATION PROBABILITY TO .5,
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   REINITIALIZE SEEDS, 2 RUNS
SIMULATE;
SIMULATE;                                REINITIALIZE SEEDS, SET DISCRIMINATION
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   PROBABILITY TO .3, 2 RUNS
INTLC,XX(11)=.3;
SIMULATE;
SIMULATE;                                REINITIALIZE SEEDS, SET DISCRIMINATION
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   PROBABILITY TO .1, 2 RUNS
INTLC,XX(11)=.1;
SIMULATE;
SIMULATE;                                SET NUMBER OF ARVS TO 7, SET
INTLC,XX(1)=7,XX(11)=.5;                 DISCRIMINATION PROBABILITY TO .5,
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   REINITIALIZE SEEDS, 2 RUNS
SIMULATE;
SIMULATE;                                REINITIALIZE SEEDS, SET DISCRIMINATION
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   PROBABILITY TO .3, 2 RUNS
INTLC,XX(11)=.3;
SIMULATE;
SIMULATE;                                REINITIALIZE SEEDS, SET DISCRIMINATION
SEEDS,Ø(1)/NO,Ø(2)/NO,Ø(3)/NO,Ø(4)/NO;   PROBABILITY TO .1, 2 RUNS
INTLC,XX(11)=.1;
SIMULATE;
FIN;
```

TABLE VIII

Three-Way ANOVA Results

```
* * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * *
                 PROB
              BY CEP
                 MIX
                 DP
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	.138	6	.023	4.901	.002
CEP	.014	2	.007	1.501	.241
MIX	.041	2	.021	4.371	.023
DP	.083	2	.042	8.832	.001
2-WAY INTERACTIONS	.065	12	.005	1.147	.367
CEP MIX	.003	4	.001	.184	.944
CEP DP	.028	4	.007	1.499	.230
MIX DP	.033	4	.008	1.756	.167
3-WAY INTERACTIONS	.007	8	.001	.184	.991
CEP MIX DP	.007	8	.001	.184	.991
EXPLAINED	.210	26	.008	1.717	.085
RESIDUAL	.127	27	.005		
TOTAL	.337	53	.006		

changed in significance and identify the most significant two-way interaction. The results are depicted in Table IX. The degrees of freedom in the error term increased and the mean square error of the error term decreased. This indicates a desirable result. The CEP is still not significant at the 95% confidence level. The two-way interactions remain insignificant. Again, a significant difference is indicated in the target area destruction produced by each mix.

TABLE IX

Three-Way ANOVA Results - Higher Interactions Confounded

```
* * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * *
                PROB
             BY CEP
                MIX
                DP
* * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * * *
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	.138	6	.023	6.025	.001
CEP	.014	2	.007	1.845	.173
MIX	.041	2	.021	5.373	.009
DP	.083	2	.042	10.857	.001
2-WAY INTERACTIONS	.065	12	.005	1.410	.208
CEP MIX	.003	4	.001	.227	.922
CEP DP	.028	4	.007	1.843	.143
MIX DP	.033	4	.008	2.159	.094
EXPLAINED	.203	18	.011	2.948	.003
RESIDUAL	.134	35	.004		
TOTAL	.337	53	.006		

Based on the resulting higher significance of the MIX-DP interaction, a two-way ANOVA was accomplished. The results are depicted in Table X. The degrees of freedom in the error term again increased and the mean square error of the error term remained the same. This, again, indicates a desirable result. The t way interactions are still not significant at the 95% level. The target area damages produced by each mix remain significantly different. In all cases, the discrimination probability of the point defense is the most significant factor in the probability of target area destruction.

TABLE X

Two-Way ANOVA Results

* * * * * * * * A N A L Y S I S   O F   V A R I A N C E * * * * * * * *
PROB
BY MIX
DP
* *

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	.124	4	.031	7.775	.001
MIX	.041	2	.021	5.147	.010
DP	.083	2	.042	10.402	.001
2-WAY INTERACTIONS	.033	4	.008	2.069	.101
MIX DP	.033	4	.008	2.069	.101
EXPLAINED	.157	8	.020	4.922	.001
RESIDUAL	.180	45	.004		
TOTAL	.337	53	.006		

In order to determine and confirm the recommended mix to answer the initial question, a Duncan's multiple-range test was accomplished at the 95% confidence level. The results are depicted in Table XI. The results indicate that there is no significant difference between the mixes of three new RVs and seven current RVs, and five new RVs and five current RVs. The mix of seven new RVs and three current RVs is significantly different from the other two. Therefore, based on this experiment and the analysis, a mix of seven new RVs and three current RVs is recommended.

TABLE XI

Duncan's Multiple Range Test Results

```
DUNCAN PROCEDURE
RANGES FOR THE .050 LEVEL -

        2.84  2.99

THE RANGES ABOVE ARE TABULAR VALUES.
THE VALUE ACTUALLY COMPARED WITH  MEAN(J)-MEAN(I) IS..
       .0538 * RANGE * SQRT(1/N(I) + 1/N(J))

HOMOGENEOUS SUBSETS  (SUBSETS OF GROUPS, WHOSE HIGHEST AND LOWEST MEANS DO
NOT DIFFER BY MORE THAN THE SHORTEST SIGNFICANT RANGE FOR A
SUBSET OF THAT SIZE)

SUBSET  1

GROUP       GRP  1       GRP  2
MEAN         .0308        .0425
- - - - - - - - - - - - - - - - -

SUBSET  2

GROUP       GRP  3
MEAN         .0943
- - - - - - - - - -
```

V Conclusions and Recommendations

Although the primary goal of this thesis was the construction of a simulation model, the development and subsequent exercise of the model have lead to some conclusions and recommendations about the general nature of the RV/ABM system. The conclusions are based both on the objectives of the thesis and on the results of the analysis of the system.

Conclusions

The three objectives of this thesis have been satisfied. First, a verified and validated simulation model has been developed that will improve the analysis of the RV/ABM engagement system. Second, a "User's Manual" for this model has been provided, by way of Appendix C, that instructs the user in model operation. Finally, an illustrative example is included that demonstrates both the flexibility of the model and the complexities of the actual system. The experimental design that is contained within the example also leads to some conclusions regarding the statistical significance of the factors in the experiment.

ICBM Load Mix. The first statistically significant factor considered is the load mix of the ICBM. Assuming the weapon system parameters contained in the model, the MRV is more effective than the BRV using a criterion of target level damage. This appears to be true for two primary reasons. The first is that the MRV is more successful at penetrating the ballistic missile defenses than the BRV. The second, and less significant, reason is that the accuracies assumed for the MRV are more precise than those assumed for the BRV.

The higher penetration success stems from two factors, the vulnerability levels of the RVs, and the probabilities of discrimination assessed for the defense. With increasing emphasis on achieving higher levels of nuclear hardness, the MRV, representing newer technology, would logically be more resistant to nuclear effects. This is much less important, however, than the lower probability of discrimination used for the MRV. As described earlier, the probability of discrimination is the summation of a great number of factors such as launch and weapon reliabilities, correct object identification and trajectory prediction, and the probability that all defensive systems function correctly during the engagement. Most of these problems for the defense are magnified when facing a maneuvering RV. Therefore, the probability of discrimination should be lower. This results in increased success at defense penetration and a greater likelihood of causing target damage.

Once at the target area, the increased accuracy of the MRV appears to at least partially offset the larger yield of the BRV. This was not statistically tested, however. What was tested, and statistically proven, is that a mix of seven MRVs with three BRVs results in a statistically significant, higher level of target damage than the other loads tested (fewer MRVs/more BRVs).

MRV Accuracy. The second factor considered is the accuracy (CEP) of the MRV. Previous analyses have identified the fact that accuracy is more important than yield in attacking hard targets (Ref 2). With targets such as the hypothetical ones of this thesis, hardened to resist several thousands of pounds of overpressure per square inch, extremely precise accuracy is required for a successful attack.

Probability of Discrimination. Perhaps the most significant result of this thesis is the identification of the criticality of the probability of discrimination for the defense. The trial runs, mentioned in Chapter III, that were used to test the assumptions of certain probability distribution functions, revealed a very important finding. If the RV was successfully identified, tracked, and engaged, it was destroyed. The weapons used by the interceptors are large enough that, when paired with the precise accuracies of the interceptors, the RVs cannot survive the vast majority of the detonations. The significance of this figure, then, leads to the conclusion that the technology to permit successful penetration to the target is as important as the technology that permits increased RV accuracy. The trial runs that resulted in forty RV kills out of forty engagements with the engagements taking place at altitudes least favorable to the defense attest to this. The statistical analysis that verified that the probability of discrimination was a statistically significant factor in determining target damage levels also is evidence for this point. This results, however, in being able to go beyond the maneuvering reentry vehicle to the conclusion that any technology that lowers the probability of discrimination should result in higher target damage levels. Better decoys and chaff, electronic counter measures, and defense suppression are all options that could decrease the probability of discrimination and should, therefore, be investigated.

The implications of this conclusion are far-reaching. The first concerns the credibility of the ICBM deterrent. The primary concern voiced about the prelaunch survivability of the ICBM and the impact that it has on the credibility only addresses one aspect of the problem. In order to be a credible deterrent, the ICBM and its RVs must be capable of successfully penetrating enemy defenses and striking their assigned targets. Without survivability in both modes, prelaunch and penetration, the credibility of the deterrent is weakened, and, thus, a destabilizing factor in the political and strategic arena is introduced. The technology is at hand for the Soviet deployment of an effective ballistic missile defense system. Those who persist in using the metaphor for that defense of "trying to hit a bullet with a bullet" have been passed by the times. The Soviets clearly believe the technology is available and their perceptions are the only ones that matter. If they feel that their defenses would be effective in preventing or limiting damage from a full-scale U.S. ICBM strike, then the ICBM deterrent is not credible and the billions of dollars that will be spent for the MX missile system will be wasted.

Recommendations

The intent of this section is to offer recommendations for further study in the topic area. It is certainly a subject deserving of more attention because of the severe impact a credible BMD has on the ICBM deterrence capability. The U.S. government is spending billions of dollars to make the Soviets believe the MX can survive an enemy first strike. That money will be nearly worthless if the Soviets do not believe the RVs the MX will deliver are survivable during penetration.

The first recommendation, therefore, is a classified study using the actual parameters and capabilities of current and future systems. Although this unclassified effort revealed much of value, the actual data were classified and could not be used. As a result, the full capabilities of the model could not be demonstrated. Along with the capabilities of U.S. systems, the refinement of actual probability of discrimination values should be possible. This critical factor is vital in analyzing BMD impact and effectiveness.

The second recommendation, and perhaps most appropriate for an AFIT thesis effort, is a study of the impact of tactics for the maneuvering RV. For example, defense suppression could have a very real impact on the number of subsequent RVs that reach the target. Suitable targets exist, such as a non-mobile acquisition radar. The effectiveness of such tactics would certainly be of interest.

A third, and related, recommendation is the evaluation of defense tactics. Commonly accepted tactics used to defeat maneuvering threats such as netting, or sending multiple interceptors after a single threat, may not be required in light of new, highly maneuverable interceptors. This would reduce the number of interceptors required per engagement, thus negating an accepted offensive tactic, exhaustion of defenses, or forcing the defense to use all interceptors early in the battle.

A final recommendation is the addition of cost considerations in the evaluation of the two competing reentry vehicle designs. This thesis used a single criterion for measuring effectiveness, the level of target damage. The addition of a second criterion would not add significant difficulty, but could add significant insight.

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APPENDICES

APPENDIX A

X-RAY AND NEUTRON FLUENCE DERIVATIONS

X-ray Calculations (Ref 4)

Two definitions should be noted prior to a discussion of the derivations behind the calculations. The first of the terms to be defined is macroscopic cross section, μ_t. Macroscopic cross section is the probability of a reaction by a single particle divided by the length of path traveled by the particle. Stated differently, it is the target atom density times the microscopic cross section. Microscopic cross section is the target area of the particle presented for interaction and is the second term to be defined.

The Attenuation Law is applicable to all streaming particles. The law states that the decrease in particle population over distance is given by

$$dn = -n(r)\mu_t dr \tag{15}$$

where n(r) is the particle population at a distance, r. The solution to this differential equation is

$$n(r) = n(0)e^{-\mu_t r} \tag{16}$$

where n(0) is the initial particle population. Including spherical divergence yields

$$n(r) = \frac{n(0)e^{-\mu_t r}}{4\pi r^2} \tag{17}$$

Applying the above to X-rays as packets of energy from a polyenergetic source yields

$$F(r) = \int \frac{S(h\nu)e^{-\mu_t r}}{4\pi r^2} \, d(h\nu) \qquad (18)$$

where

$F(r)$ = X-ray energy fluence at distance r in calories per square centimeter

$S(h\nu)$ = Planckian source spectrum in calories per thousand electron volts

μ_t = macroscopic cross section of air, which is also a function of X-ray energy ($h\nu$)

A build up factor (BUF) is included in the above equation due to the scattering of the X-rays by the air yielding

$$F(r) = \int \frac{(BUF)S(h\nu)e^{-\mu_t r}}{4\pi r^2} \, d(h\nu) \qquad (19)$$

The nuclear bomb is a black body radiator and, therefore, the Planckian spectrum, represented by Figure 12, describes the source. Planck's spectrum is defined by the function

$$S(h\nu) = \frac{15}{kT^4 \pi^4} \; \frac{(h\nu)^3}{e^{(h\nu/kT)} - 1} \qquad (20)$$

yielding the density function in Figure 12,

where

$h\nu$ = energy of the X-rays

kT = kinetic temperature of the X-rays

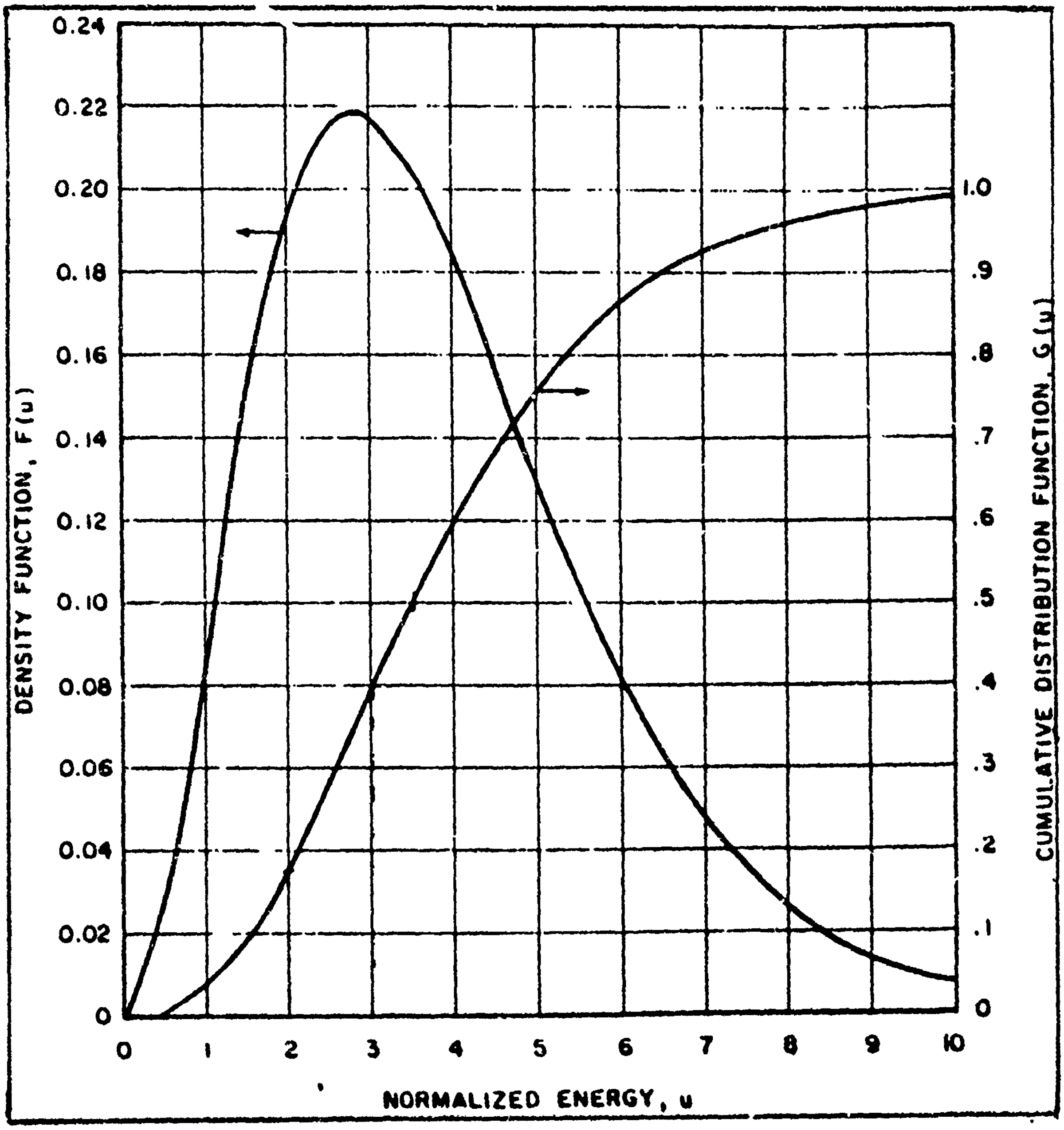


Fig 12. The Planck Function and Its "ntegral (Ref 4)

Integrating the above equation yields the cumulative distribution function in Figure 12 as follows

$$G(h\nu) = \frac{15}{kT^4\pi^4}\int_0^{h\nu} \frac{(h\nu)^3}{e^{(h\nu/kT)} - 1}\, d(h\nu) \qquad (21)$$

$$G(\infty) = \frac{15}{\pi^4}\int_0^{\infty} \frac{(h\nu/kT)^3}{e^{(h\nu/kT)} - 1}\, d(h\nu/kT) = 1 \qquad (22)$$

Letting $x = h\nu/kT$ to normalize the X-ray energy yields

$$G(x) = \frac{15}{\pi^4}\int_0^{x} \frac{x'^3}{e^{x'} - 1}\, d(x') \qquad (23)$$

Setting $G(x)$ equal to .1, .2, .3, .4, .5, .6, .7, .8, .9, and 1, and solving

$$G(x) = \frac{15}{\pi^4}\int_0^{x_i} \frac{x'^3}{e^{x'} - 1}\, d(x') \qquad (24)$$

for x_i yields x_i equal to 1.54, 2.1, 2.58, 3.04, 3.5, 4.02, 4.62, 5.38, 6.56, and 10, respectively. This yields 10 equal energy groups with 10% of the energy in each group as follows:

group 1 - 0-1.54
group 2 - 1.54-2.1
group 3 - 2.1-2.58
group 4 - 2.58-3.04
group 5 - 3.04-3.5
group 6 - 3.5-4.02
group 7 - 4.02-4.62
group 8 - 4.62-5.38
group 9 - 5.38-6.56
group 10 - 6.56-10

Finding the midpoint of each group yields

group 1 - .77
group 2 - 1.82
group 3 - 2.34
group 4 - 2.81
group 5 - 3.27
group 6 - 3.76
group 7 - 4.32
group 8 - 5.0
group 9 - 5.97
group 10 - 8.28

Therefore, knowing the kinetic temperature of the source X-rays, the source can be related to the normalized midpoints, x_i, as follows

$$(h\nu)_i = x_i(kT) \qquad (25)$$

Due to the leakage, the upper limit on the X-ray yield is approximately 80% of the total yield of the weapon. Thus the total X-ray energy possible in calories per square centimeter is

$$S(h\nu) = .8 \text{ (yield)} \qquad (26)$$

where the yield is in kilotons and one kiloton is equal to 10^{12} calories. Note that $\sum_{i=1}^{10} S_i = 1$; therefore, $\sum_{i=1}^{10} S_i(.8)$ (yield) = $S(h\nu)$. Thus $S_i = 1$. Note also that $S(h\nu)$ is not a function of range.

In the above equation, $e^{-\mu_t r}$ is equal to $e^{-(\mu_t/\rho)(\rho r)}$ where μ_t/ρ is the X-ray attenuation coefficient for air in square centimeters per gram. This coefficient is a function of X-ray energy, $h\nu$, and is different for each of the 10 energy groups just mentioned. The attenuation coefficient for each group as a function of hv_i in square centimeters per gram is given by

$$(\mu_t/\rho)_i = -.001354 + 19.7564/(hv)_i - 461.763/(hv)_i^2 + 6680.02/(hv)_i^3 - 3497.36/(hv)_i^4 + 907.358/(hv)_i^5 \quad (27)$$

where

ρ = density of the air in kilograms per cubic meter

r = range from burst to target in kilometers

The density of the air times the range is known as the mass integral. The mass integral is a function of the altitude of the burst, the altitude of the target, and the range between the target and the burst. If the burst and the target are at the same altitude, the mass integral is a constant for all groups given an altitude and a range of the engagement, and is in units of grams per square centimeter.

BUF is a function of μ_t/ρ and is different for each of the 10 energy groups. BUF is unitless and is given by

$$BUF_i = A1e^{c_1(\mu_t/\rho)_i(\rho r)} + A2e^{c_2(\mu_t/\rho)_i(\rho r)} \quad (28)$$

where A1, c_1, and c_2 are dependent on hv_i and are given in Tabel XII. In addition, A2 = 1 - A1. The above equation for BUF is a fit for Figure 13.

Knowing that

TABLE XII

Constants for Empirical Build-up Factor Equation (Ref 4)

Energy in keV	A_1	A_2	c_1	c_2	Maximum % difference below 8 MFP
12	-0.227	1.227	-0.400	0.000	0.35 %
14	-0.370	1.370	-0.400	0.000	0.89 %
16	-0.323	1.323	-0.680	0.020	1.78 %
18	-0.634	1.634	-0.460	0.020	0.91 %
20	-1.072	2.072	-0.360	0.020	2.71 %
22	-1.048	2.048	-0.480	0.040	2.90 %
24	-1.740	2.748	-0.340	0.040	0.75 %
26	-2.673	3.673	-0.260	0.040	1.85 %
28	-2.664	3.664	-0.300	0.060	3.87 %
30	-6.038	7.038	-0.140	0.040	2.90 %
32	-8.805	9.805	-0.100	0.040	1.45 %
34	-8.504	9.504	-0.100	0.060	1.63 %
36	-75.83	76.83	0.000	0.020	0.97 %
38	-20.03	21.03	-0.020	0.060	3.77 %
40	-16.94	17.94	-0.020	0.080	6.93 %
45	14.59	-13.59	0.120	-0.020	13.7 %
50	11.31	-10.31	0.160	-0.040	21.1 %
55	109.2	-108.2	0.120	0.100	18.0 %
60	-11.05	12.05	0.000	0.200	26.6 %
70	-114.1	115.1	0.140	0.160	25.7 %
80	-113.1	114.1	0.160	0.180	27.6 %
100	-10.93	11.93	0.060	0.260	36.0 %
120	-8.153	9.153	0.020	0.280	39.1 %
150	13.14	-12.14	0.260	0.100	36.3 %
200	-88.92	89.92	0.180	0.200	33.1 %
250	-6.308	7.308	0.000	0.260	39.9 %
300	19.89	-18.89	0.200	0.120	33.1 %
350	72.37	-71.37	0.160	0.140	31.2 %
400	-6.063	7.063	0.000	0.220	35.1 %
500	16.29	-15.29	0.160	0.080	28.8 %
600	-57.58	57.58	0.100	0.120	25.7 %
750	-17.20	18.20	0.060	0.120	22.6 %

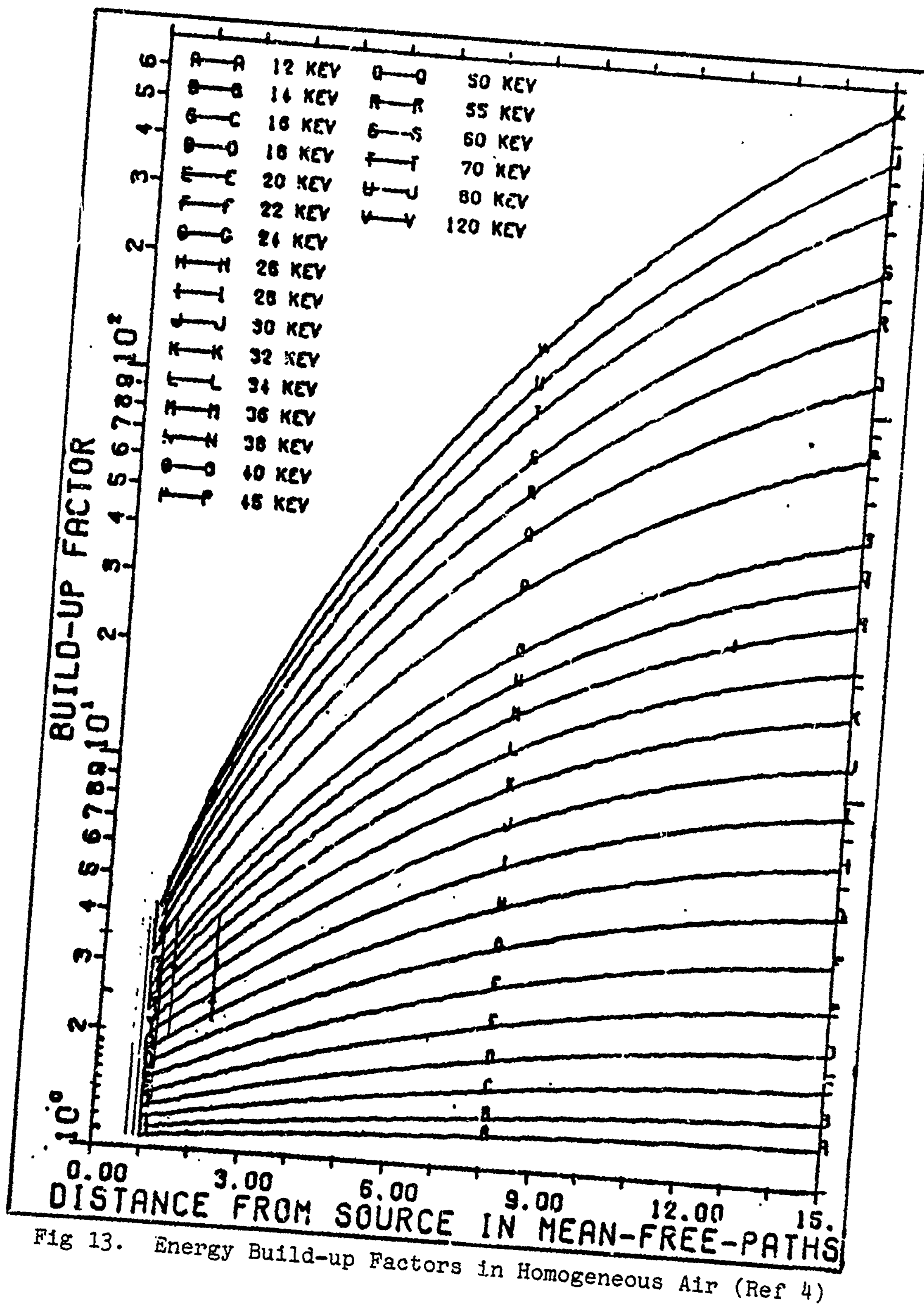


Fig 13. Energy Build-up Factors in Homogeneous Air (Ref 4)

$$F(r) = \int \frac{(BUF)S(hv)e^{-\mu_t r}}{4\pi r^2} d(hv) \qquad (29)$$

and transforming F(r) into a discrete function with

$$BUF = \sum_{i=1}^{10} BUF_i \qquad (30)$$

$$S(hv) = \sum_{i=1}^{10} S_i(.8)(yield) \qquad (31)$$

where S_i = .1 and

$$e^{-\mu_t r} = e^{-(\mu_t/\rho)(\rho r)} = \sum_{i=1}^{10} e^{-(\mu_t/\rho)_i(\rho r)} \qquad (32)$$

yields

$$F(r) = \frac{.8(yield)}{4\pi r^2} \sum_{i=1}^{10} (.1)(BUF)_i(e^{-(\mu_t/\rho)_i(\rho r)}) \text{ cal/cm}^2 \qquad (33)$$

This formulation is good for X-rays with kinetic temperatures which are greater than or equal to a few thousand electron volts because it ignores scatter.

User Function 6 uses the above X-ray equations. Two assumptions were made concerning the X-ray fluence on the target. The first of these is that the atmosphere is homogeneous. The second is that X-rays are considered damaging above 70,000 feet, only. Given the yield in kilotons, the temperature of the source X-rays in kT, and the range from the burst to target in feet, the FORTRAN code in User Function

6 first calculates the yield in calories as follows

$$\text{yield(cal)} = \text{yield(kilotons)}(10^{12} \text{ calories/kiloton}) \quad (34)$$

The range is then converted to kilometers as follows

$$r(\text{km}) = r(\text{ft})(.00030480 \text{ km/ft}) \quad (35)$$

The mass integral is then computed by

$$\rho r(\text{gm/cm}^2) = \rho(\text{kg/m}^3)r(\text{km})(10^3 \text{ gm/kg})(10^5 \text{ cm/km})(10^{-6} \text{ m}^3/\text{cm}^3) \quad (36)$$

$$= \rho(\text{kg/m}^3)r(\text{km})(10^2) \quad (37)$$

where ρ is the density of the air at the intercept altitude. For each of the 10 groups, $h\nu_i$ is computed using Eq (25), and $(\mu_t/\rho)_i$ is computed using Eq (27). An iterative routine is then accomplished to find the nearest hv in Table XII to $h\nu_i$. The hv value obtained is then used to obtain A1, A2, c_1, and c_2. BUF_i is then computed using Eq (28). For each of the ten groups, a value is computed by $(.1)(BUF)_i e^{-(\mu_t/\rho)_i(\rho r)}$. As each value is obtained for a group, they are summed to obtain the sum for all 10 groups. The range is then converted to centimeters as follows

$$r(\text{cm}) = r(\text{km})(10^5 \text{ cm/km}) \quad (38)$$

Finally, the total X-ray fluence on target is computed using Eq (33). It should be noted that if $h\nu_i$ is less than 12, BUF_i is set equal to 1.

Neutron Calculations (Ref 4)

In contrast with X-rays, the Attenuation Law is not applicable to neutrons. Therefore, Eq (39) represents

$$F(x) = \frac{3.16E23\ (\text{neutrons/kiloton})\text{yield}(\text{kilotons})S(x)}{4\pi r(\text{cm})^2} \quad (39)$$

the neutron fluence on the target in neutrons per square centimeter. The above equation assumes a thermonuclear yield which produces 3.16E23 neutrons per kiloton of yield.

Absorption of neutrons by the atmosphere is not likely. Therefore, scatter dominates. The repeated scattering and resulting energy loss implies that the average energy of the neutrons decreases as time and distance form the burst increase. The procedure, then, for determining the neutron fluence per source neutron, S(x), at a particular range is to find the fluence in homogeneous air and then apply the result to every point in the real atmosphere which lies on the same mass range from the burst point. This procedure assumes that spherical divergence and neutron attenuation are separable, which they are not. Sizeable error results for altitudes from 5 to 25 kilometers. However, the code which is currently popular uses this procedure and the results are good.

S(x) is, then, a function of the mass integral, ρr. Once again, the density of the air, ρ, varies with altitude. If the burst and the target are coaltitude, the mass integral is determined given the altitude and the range of the engagement, and is in units of grams per square centimeter.

S(x) as a function of the mass integral is given by

$$S(x) = \exp[A + B(\rho r) + C(\rho r)^2 + D(\rho r)^{1.5} + E(\rho r)^{.5} + F(\rho r)^{1/3} + G\ln(\rho r)] \qquad (40)$$

The variables A through G are determined from Table XIII for the neutron fluence from a thermonuclear source. The above equation is an empirical fit for Figure 14.

User functions 6 and 7 use the above neutron equations. An additional assumption made in the above calculations is that the atmosphere is homogeneous and exponential. Given the yield of the weapon in kilotons and the range from the burst to the target in feet, the FORTRAN code in User Functions 6 and 7 first converts the range to kilometers using Eq (35). The mass integral is then computed using Eq (37). Next, S(x) is computed using

$$S(x) = \exp[-6.775 + .005296(\rho r) - .000005346(\rho r)^2 - .00021468(\rho r)^{1.5} - 3.8214(\rho r)^{.5} + 10.875(\rho r)^{1/3} - 1.3975\ln(\rho r)] \quad (41)$$

The range is then converted to centimeters using Eq (38). Finally, the total neutron fluence on target is computed using Eq (39).

<u>Overpressure Calculations</u> (Ref 4)

The miss distance of the weapon is scaled down to a

TABLE XIII

ANISN Homogeneous Air Data (Ref 4)

NEUTRONS

DOSE	SOURCE	A	B	C	D	E	F	G
SILICON	THERMONUCLEAR	-.20795E+02	-.97296E-01	-.17913E-04	.15771E-02	.17924E+01	-.37101E+01	.23746E+00
TISSUE	THERMONUCLEAR	-.19711E+02	-.99348E-01	-.22342E-04	.19226E-02	.13159E+01	-.15135E+01	-.84022E-02
FLUENCE	THERMONUCLEAR	-.67750E+01	.52690E-02	-.54364E-05	-.21468E-03	-.39214E+01	.10875E+02	-.11975E+01
SILICON	FISSION	-.21780E+02	-.16126E+00	-.46917E-04	.33861E-02	.27024E+01	-.41190E+01	.21249E+00
TISSUE	FISSION	-.18463E+02	-.17636E+00	-.53973E-04	.44464E-02	.29502E+01	-.40993E+01	.17644E+00
FLUENCE	FISSION	.79627E+00	-.22572E+00	-.73701E-04	.61127E-02	.33426E+01	-.37018E+01	-.30794E-01

SECONDARY GAMMAS

DOSE	SOURCE	A	B	C	D	E	F	G
SILICON	THERMONUCLEAR	-.25281E+02	-.90153E-01	-.27961E-04	.23939E-02	.95659E+00	-.11394E+01	.98116E+00
TISSUE	THERMONUCLEAR	-.25564E+02	-.79950E-01	-.24566E-04	.21001E-02	.65711E+00	-.57599E+00	.93271E+00
FLUENCE	THERMONUCLEAR	-.48600E+01	-.11511E+00	-.37267E-04	.31772E-02	.13350E+01	-.13011E+01	.95495E+00
SILICON	FISSION	-.26416E+02	-.16697E+00	-.56993E-04	.49224E-02	.25356E+01	-.35154E+01	.10916E+01
TISSUE	FISSION	-.26313E+02	-.16452E+00	-.55756E-04	.47309E-02	.25300E+01	-.34007E+01	.11093E+01
FLUENCE	FISSION	-.57439E+01	-.16896E+00	-.55243E-04	.47643E-02	.25725E+01	-.33967E+01	.11099E+01

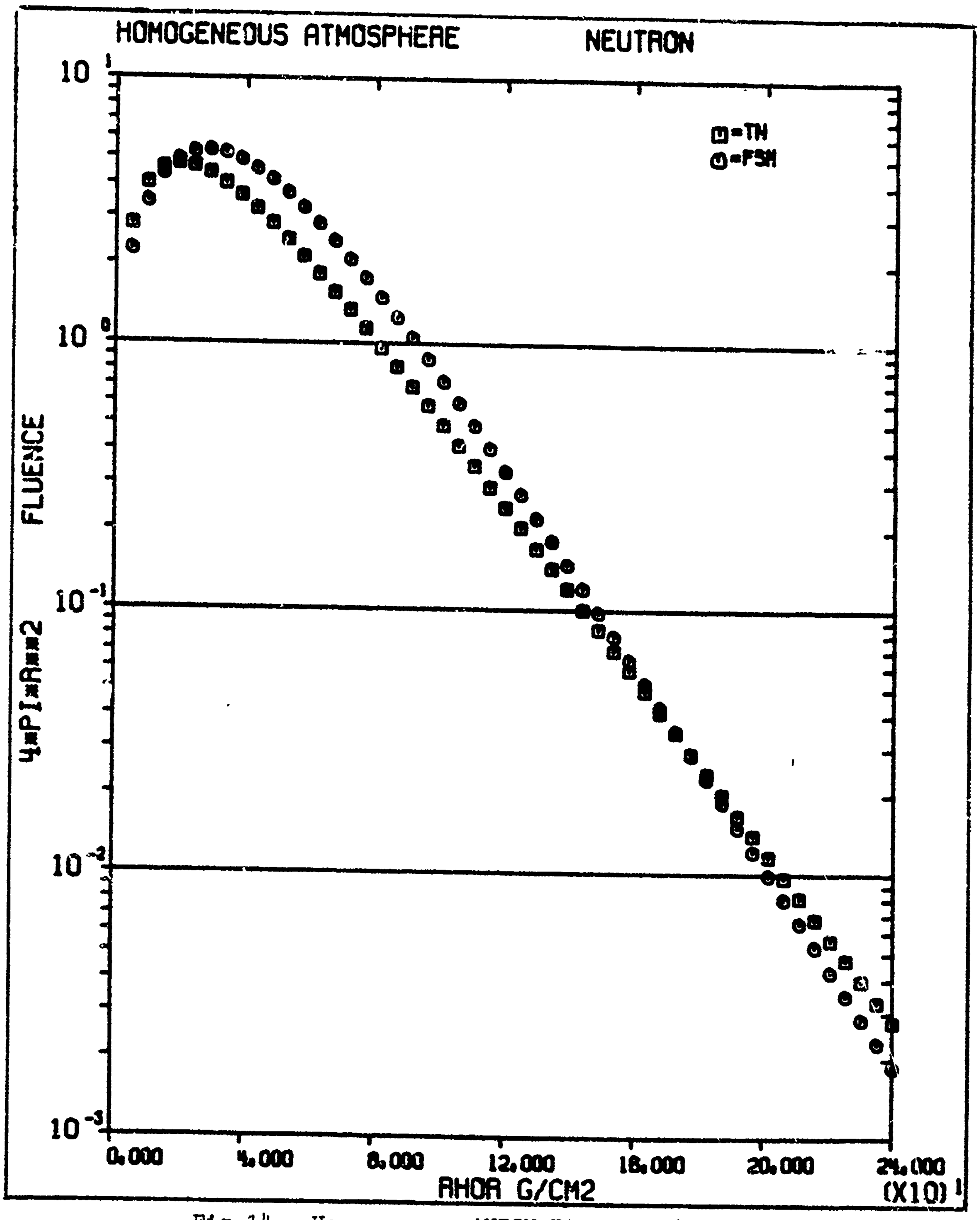


Fig 14. Homogeneous ANISN Fit Data (Ref 4)

yield of one kiloton, the reference for graphs and empirical calculations by

$$\text{range} = \text{range}/\text{yield}^{1/3} \qquad (42)$$

The height of the burst and the target are assumed to be zero at sea level. User Function 8 uses an empirical fit for Figure 15 to compute the overpressure placed on the target by an RV.

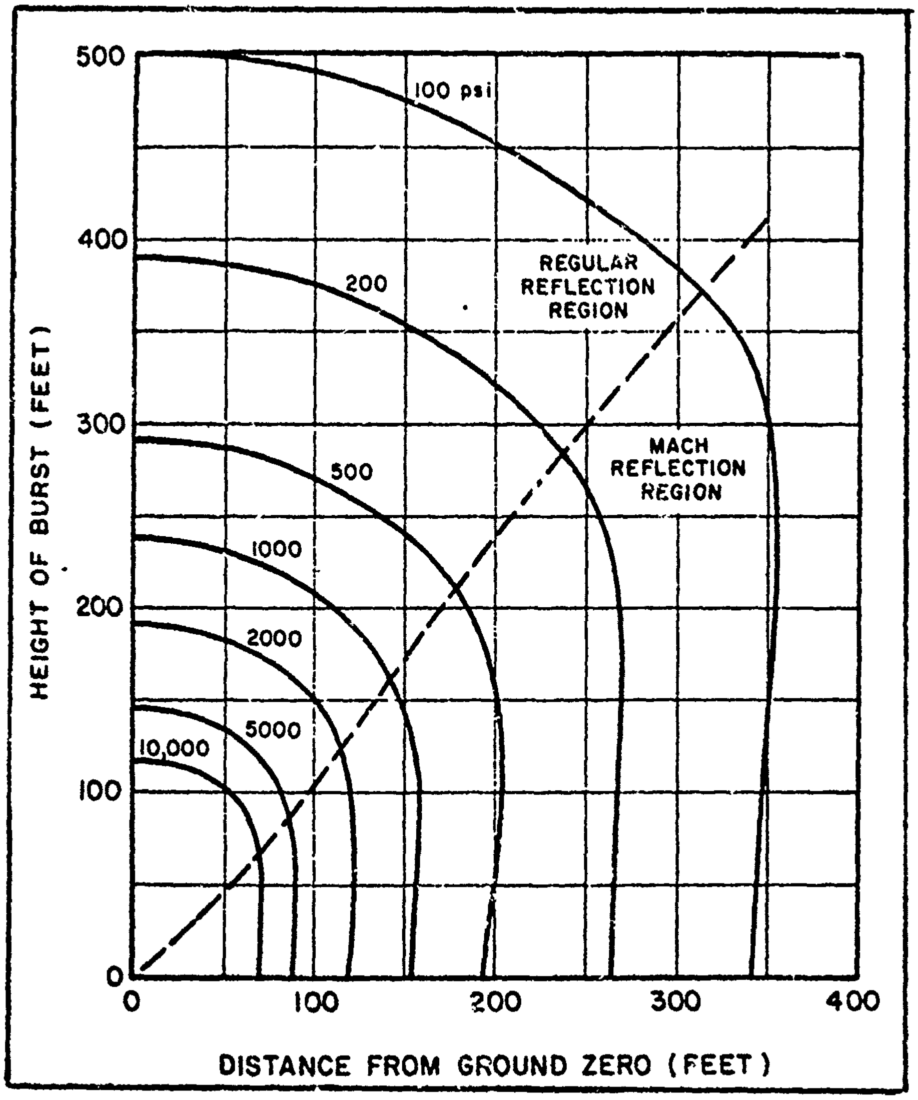


Fig 15. Peak Overpressures on the Ground for a 1 kt Burst (Ref 9:111)

APPENDIX B

CONTINUOUS DAMAGE FUNCTIONS AND WEAPON RADIUS DERIVATIONS

Damage Functions (Ref 4; 25:346-362)

Continuous damage functions were defined and used to evaluate the X-ray fluence, neutron fluence, and overpressure on the target. For X-ray and neutron fluences, the functions are based on the ranges of the damage mechanism. For overpressure, the function is based on the intensity of the damage mechanism. In all cases, the damage function is based on a lognormal probability distribution function where

P_d = probability of damage

R = range

I = intensity

$R_{.5}$ = range for 50% P_d

$I_{.5}$ = intensity for 50% P_d

The lognormal function is given by

$$f(x) = \frac{1}{\sigma x\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln x - \mu}{\sigma}\right)^2} \qquad (43)$$

where μ and σ are for the corresponding normal distribution.

Considering intensity first, the cumulative function is given by

$$P_d(I) = \int_0^I \frac{1}{\sigma I\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln I - \mu}{\sigma}\right)^2} \qquad (44)$$

Letting $z = (\ln I - \mu)/\sigma$ yields

$$\ln I = z\sigma + \mu \qquad (45)$$

$$I = e^{(z\sigma + \mu)} \tag{46}$$

When I = 0, z = $-\infty$, and dz = dI/σI. Therefore,

$$P_d(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \tag{47}$$

The sure kill intensity, I_{sk}, is defined as the intensity at which the target is killed 98% of the time. The sure safe intensity, I_{ss}, is defined as the intensity at which the target is killed 2% of the time. Thus,

$$.98 = \int_{-\infty}^{(\ln I_{sk} - \mu)/\sigma} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \tag{48}$$

$$.02 = \int_{-\infty}^{(\ln I_{ss} - \mu)/\sigma} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \tag{49}$$

From standard normal tables, z = 2.054 when $P_d(z)$ = .98 and z = -2.054 when $P_d(z)$ = .02. Therefore,

$$2.054 = \frac{\ln I_{sk} - \mu}{\sigma} \tag{50}$$

$$-2.054 = \frac{\ln I_{ss} - \mu}{\sigma} \tag{51}$$

or

$$2.054\sigma = \ln I_{sk} - \mu \tag{52}$$

$$-2.054\sigma = \ln I_{ss} - \mu \tag{53}$$

Solving Eqs (52) and (53) simultaneously for μ yields

$$0 = \ln I_{sk} + \ln I_{ss} - 2\mu \tag{54}$$

$$2\mu = \ln I_{sk} + \ln I_{ss} \tag{55}$$

$$\mu = \tfrac{1}{2}\ln(I_{sk} I_{ss}) \tag{56}$$

Solving Eqs (52) and (53) simultaneously for σ yields

$$2(2.054)\sigma = \ln I_{sk} - \ln I_{ss} \tag{57}$$

$$\sigma = \frac{1}{2(2.054)} \ln(I_{sk}/I_{ss}) \tag{58}$$

Thus, knowing the intensity for sure kill, the intensity for sure safe, and the intensity on target

$$z = \frac{\ln I - \mu}{\sigma} \tag{59}$$

where μ and σ are computed from Eqs (56) and (58), respectively.

Having computed z, the following equation can be used to approximate $P_d(z)$

$$P_d(z) = .5(1 + .196854z + .115194z^2 + .000344z^3 + .019527z^4)^{-4} \tag{60}$$

If z is less than 0, z in Eq (60) is set to the absolute value of the computed z. If z is greater than or equal to 0,

$$P_d(z) = 1 - \text{Eq (60)} \tag{61}$$

User Function 8 uses this intensity approach to calculate the probability of damage of an RV against a target where I_{ss} = 2000 pounds per square inch and I_{sk} = 6000 pounds per square inch.

A related, but different approach, was used to calculate the probability of damage of the ABM against the RV. A concept known as weapon radius (WR) was used. Weapon radius is the "cookie cutter" radius that will destroy the same number of targets as does the actual probability distribution function. The weapon radius depends on the I_{ss} and I_{sk} of the target as well as the yield of the weapon. The weapon must burst/impact within the weapon radius to kill the target. Weapon radius calculations assume homogeneously distributed, identical targets and a given probability distribution of damage, $P_d(R)$.

Range, rather than intensity, is used in developing the weapon radius where

$$\pi(WR)^2 = \int_0^\infty P_d(R) 2\pi R dR \tag{62}$$

$$(WR)^2 = \int_0^\infty P_d(R) 2R dR \tag{63}$$

Integrating Eq (63) by parts, letting $u = P_d(R)$ and $dv = 2RdR$, yields

$$du = \frac{d(P_d(R))}{dR} \tag{64}$$

$$v = R^2 \tag{65}$$

Therefore,

$$(WR)^2 = [R^2 P_d(R)]_0^\infty - \int_0^\infty R^2 \frac{d(P_d(R))}{dR} dR \qquad (66)$$

However,

$$0 = [R^2 P_d(R)]_0^\infty \qquad (67)$$

Therefore,

$$(WR)^2 = \int_0^\infty R^2 \frac{d(P_d(R))}{dR} dR \qquad (68)$$

Again basing the damage function on a lognormal probability distribution yields

$$(WR)^2 = \int_0^\infty R^2 \frac{1}{\sigma R\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln R - \mu}{\sigma}\right)^2} dR \qquad (69)$$

Letting $z = (\ln R - \mu)/\sigma$ yields

$$\ln R = z\sigma + \mu \qquad (70)$$

$$R = e^{(z\sigma + \mu)} \qquad (71)$$

When $R = 0$, $z = -\infty$, and $dz = dR/R\sigma$. Therefore,

$$(WR)^2 = \int_{-\infty}^\infty e^{(2z\sigma + 2\mu)} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \qquad (72)$$

$$(WR)^2 = e^{2\mu} \int_{-\infty}^\infty e^{2z\sigma} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}z^2} dz \qquad (73)$$

$$(WR)^2 = e^{2\mu} \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(z^2 - 4z\sigma)} dz \qquad (74)$$

$$(WR)^2 = e^{2\mu} \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{\frac{1}{2}(4\sigma^2)} e^{-\frac{1}{2}(z^2 - 4z\sigma + 4\sigma^2)} dz \qquad (75)$$

$$(WR)^2 = e^{(2\mu + 2\sigma^2)} \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}(z - 2\sigma)^2} dz \qquad (76)$$

Letting $w = z - 2\sigma$ and $dw = dz$ yields

$$(WR)^2 = e^{2(\mu + \sigma^2)} \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}w^2} dw \qquad (77)$$

However,

$$1 = \int_{-\infty}^{\infty} \frac{1}{\sqrt{2\pi}} e^{-\frac{1}{2}w^2} dw \qquad (78)$$

Therefore,

$$(WR)^2 = e^{2(\mu + \sigma^2)} \qquad (79)$$

$$WR = e^{(\mu + \sigma^2)} \qquad (80)$$

Since

$$P_d(r) = \int_{0}^{R} \frac{1}{\sigma R\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{\ln R - \mu}{\sigma}\right)^2} dR \qquad (81)$$

μ and σ can be expressed as functions of the range of sure kill, R_{sk}, and the range of sure safe, R_{ss}, just as in the intensity case previously developed. This yields

$$\mu = .5\ln(R_{sk}R_{ss}) \tag{82}$$

$$\sigma = \frac{1}{2(2.054)} \ln(R_{sk}/R_{ss}) \tag{83}$$

Knowing the intensity for sure kill and the intensity for sure safe, the X-ray and neutron calculation routines in User Functions 6 and 7 are accomplished for different ranges to determine the ranges at which the sure safe and sure kill intensities are realized. Having R_{ss} and R_{sk}, WR can be computed for the particular encounter using Eq (80).

Prior to further development of this damage function, four assumptions must be made explicit. The first of these is that the target is in the burst plane. The second is that the height of the burst is controllable such that $\sigma_z = 0$. The third is that variations in missing in the x and y directions are equal such that $\sigma_x = \sigma_y$. Finally, the distributions in the x and y directions are normal. Therefore,

$$f(x) = \frac{1}{\sigma_x\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{x}{\sigma_x}\right)^2} \tag{84}$$

$$f(y) = \frac{1}{\sigma_y\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2} \tag{85}$$

Thus, f(x,y) for a differential area dA is given by

$$f(x,y) = \frac{1}{\sigma^2 2\pi} e^{-\frac{1}{2}\left(\frac{x^2 + y^2}{\sigma^2}\right)} \tag{86}$$

Transforming into the circular normal function yields

$$f(r,\theta) = \frac{1}{\sigma^2 2\pi} e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} r \tag{87}$$

The cumulative function is given by

$$F(r,\theta) = \int_0^{2\pi} \int_0^r \frac{1}{\sigma^2 2\pi} e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} r dr d\theta \tag{88}$$

Integrating with respect to θ yields

$$F(r) = \int_0^r \frac{1}{\sigma^2} e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} r dr \tag{89}$$

$$F(r) = 1 - e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} \tag{90}$$

Circular error probable (CEP) by definition is the point at which the cumulative function is equal to .5.

Therefore,

$$.5 = \int_0^{CEP} \frac{r}{\sigma^2} e^{-\frac{1}{2}\left(\frac{r}{\sigma}\right)^2} dr \tag{91}$$

$$.5 = 1 - e^{-\frac{1}{2}\left(\frac{CEP}{\sigma}\right)^2} \tag{92}$$

$$.5 = e^{-\frac{1}{2}\left(\frac{CEP}{\sigma}\right)^2} \tag{93}$$

$$\ln .5 = -\frac{1}{2} \frac{CEP^2}{\sigma^2} \tag{94}$$

$$-2\ln .5 = -\frac{CEP^2}{\sigma^2} \tag{95}$$

$$CEP^2 = (2\ln 2)\sigma^2 \quad (96)$$

$$CEP = \sqrt{2\ln 2}\ \sigma \quad (97)$$

$$\sigma = \frac{CEP}{2\ln 2} \quad (98)$$

Substituting Eq (98) into Eq (90) yields

$$F(r) = 1 - e^{-\frac{1}{2}\left(\frac{r\sqrt{2\ln 2}}{CEP}\right)^2} \quad (99)$$

$$F(r) = 1 - e^{-\frac{1}{2}\left(\frac{(2\ln 2)r^2}{CEP^2}\right)} \quad (100)$$

$$F(r) = 1 - e^{-\ln 2\left(\frac{r}{CEP}\right)^2} \quad (101)$$

$$F(r) = 1 - e^{-.693\left(\frac{r}{CEP}\right)^2} \quad (102)$$

The single shot probability of kill (P_{ssk}) can be computed if the weapon radius and CEP of the weapon are known by substituting WR into Eq (102) for r, yielding

$$P_{ssk} = 1 - e^{-.693\left(\frac{WR}{CEP}\right)^2} \quad (103)$$

In other words, P_{ssk} is the probability that the weapon impacts within radius WR if the CEP of the weapon is known. This weapon radius rationale is used in User Functions 6 and 7.

<u>Aiming Errors</u> (Ref 25:346-362)

As developed previously, the aiming errors in the xy plane are assumed to be independent and normally distributed with equal variance and zero mean. Therefore, the distribution of miss distances is given by the Rayleigh distribution or circular normal function, Eq (87). The cumulative function as a function of CEP is given by Eq (102). Solving Eq (102) for r yields

$$r = \frac{CEP^2 \ln[1 - F(r)]}{-.693} \tag{104}$$

The cumulative distribution function, F(r), is uniformly distributed between zero and one. User Functions 6, 7, and 8 make use of this fact to compute ABM and RV miss distances. On any given encounter, a uniformly distributed random number between zero and one is drawn and substituted into Eq (104) for F(r). Based on the CEP of the weapon, the miss distance, r, for that encounter may be computed.

APPENDIX C

MODEL OPERATION (REF 17)

Introduction

This appendix contains information for the person using the RV/ABM engagement model developed in this thesis. A knowledge of the simulation language, SLAM, while helpful, is not required. The appendix shows the job control language required for the CDC6600, at AFIT, and the methods of changing the weapon system parameters for the offense and defense. Little adjustment to the actual network is illustrated because the possibilities are endless once the basic structure is modified. The design of the model is such that there is sufficient flexibility to model a wide variety of situations within the existing structure. However, the user must have access to the classified information necessary to take full advantage of the capabilities of the model.

The model can be utilized to answer and analyze questions posed by both the offense and the defense. The model is capable of handling an analysis of situations involving one RV type or two RV types, delivered to the target in any numbers and mixes desired. The type of defense can range from none at all to a layered terminal defense, composed of an endo-atmospheric and point defense system. The target area can consist of any fixed, homogeneous target set.

The SLAM portion of the model is developed in six segments. These segments are discussed in the following six sections. Each section contains a brief description of that segment's operation, the SLAM network structure, and the SLAM computer code for that segment with a line by line interpretation of the SLAM computer code. The SLAM code included here is the code for the example experiment in Chapter IV. Following these six sections is a listing of the commented FORTRAN user functions. The subroutines are called and controlled by the SLAM code. For a more complete discussion of the user functions, refer to Appendices A and B. Table XIV is a key to the attributes and variables to be referred to in the following discussion. Any further changes beyond those indicated would require alterations of the SLAM network and/or supporting subroutines. With the aid of this appendix and the example experiment in Chapter IV, the user should be able to analyze a wide variety of RV/ABM issues.

Arriving RVs

The first node, START, simulates the normally distributed release of a specific number of entities, RVs and decoys, from the post-boost vehicle. Each entity is released as if it was an RV. For example, if a decoy weighs 10 pounds and the RV weighs 100 pounds, one RV position could be used for 10 decoys. Assuming the post-boost vehicle capacity is 10 RVs, the post-boost vehicle could carry 10 RVs, 9 RVs and 10 decoys, 8 RVs and 20 decoys, etc. The number of entities in each case, however, is 10.

At node N1, the entities are counted. Depending on the entity count, the entity is then designated as an RV of the first type, an ARV, at node ARV, an RV of the second type, a BRV, at node BRV, or a set of decoys at node N2. All RVs

TABLE XIV

Attribute and Global Variable Key

```
;ATTRIBUTE KEY
;   1 = MARK TIME
;   2 = RV TYPE (1 = ARV, 2 = BRV)
;   3 = TIME TO FLY 150,000 FT TO 70,000 FT THRU ENDO DEFENSE ZONE
;       FROM USERF 1
;   4 = TIME TO INTERCEPT IN ENDO ZONE FROM USERF 2
;   5 = TIME TO FLY 70,000 FT TO 10,000 FT THRU POINT DEFENSE ZONE
;       FROM USERF 3
;   6 = TIME TO INTERCEPT IN POINT ZONE FROM USERF 4
;   7 = PROBABILITY OF ABM KILLING RV IN ENDO OR POINT ZONES
;       FROM USERF 6 OR 7
;   8 - 14 = UNIFORM RANDOM NO (0 TO 1) TO ACHIEVE CORRELATED SAMPLING
;
;GLOBAL VARIABLE KEY
;   XX(1) = NO OF ARVS
;   XX(2) = ARV REENTRY ANGLE IN DEGREES
;   XX(3) = BRV REENTRY ANGLE IN DEGREES
;   XX(4) = SWITCH FOR ENDO DEFENSE (0 = ENDO PRESENT, 1 = ENDO ABSENT)
;   XX(5) = NOT USED (INITIALIZED TO 1)
;   XX(6) = PROBABILITY THAT ENDO DETECTS ARV
;   XX(7) = VELOCITY OF RV IN FT/SEC
;   XX(8) = PROBABILITY THAT ENDO DETECTS BRV
;   XX(9) = TEMPERATURE OF X-RAYS FROM ENDO ABM IN KEV
;   XX(10) = SWITCH FOR POINT DEFENSE (0 = POINT PRESENT, 1 = POINT ABSENT)
;   XX(11) = PROBABILITY THAT POINT DETECTS ARV
;   XX(12) = SURE SAFE NEUTRON INTENSITY FOR ARV IN NEUTRONS/CM2
;   XX(13) = PROBABILITY THAT POINT DETECTS BRV
;   XX(14) = SURE KILL NEUTRON INTENSITY FOR ARV IN NEUTRONS/CM2
;   XX(15) = PROBABILITY OF TARGET DESTRUCTION (INITIALIZED TO 0)
;   XX(16) = NOT USED (INITIALIZED TO 0)
;   XX(17) = YIELD OF ENDO INTERCEPTOR IN KILOTONS
;   XX(18) = CEP OF ENDO INTERCEPTOR IN FEET
;   XX(19) = YIELD OF POINT INTERCEPTOR IN KILOTONS
;   XX(20) = CEP OF POINT INTERCEPTOR IN FEET
;   XX(21) = YIELD OF ARV IN FEET
;   XX(22) = CEP OF ARV IN FEET
;   XX(23) = YIELD OF BRV IN KILOTONS
;   XX(24) = CEP OF BRV IN FEET
;   XX(25) = COUNTER FOR GENERATED RVS (INITIALIZED TO 0)
;   XX(26) = TOTAL NO OF RVS ON BOOSTER
;   XX(27) = SURE SAFE X-RAY INTENSITY FOR ARV IN CALORIES/CM2
;   XX(28) = SURE KILL X-RAY INTENSITY FOR ARV IN CALORIES/CM2
;   XX(29) = SURE SAFE NEUTRON INTENSITY FOR BRV IN NEUTRONS/CM2
;   XX(30) = SURE KILL NEUTRON INTENSITY FOR BRV IN NEUTRONS/CM2
;   XX(31) = SURE SAFE X-RAY INTENSITY FOR BRV IN CALORIES/CM2
;   XX(32) = SURE KILL X-RAY INTENSITY FOR BRV IN CALORIES/CM2
;   XX(33) = SURE SAFE OVERPRESSURE FOR TARGET
;   XX(34) = SURE KILL OVERPRESSURE FOR TARGET
;
```

of the first type are introduced into the system prior to release of any RVs of the second type. At node N2, the decoys are assumed to be stripped away and do not enter the remainder of the system.

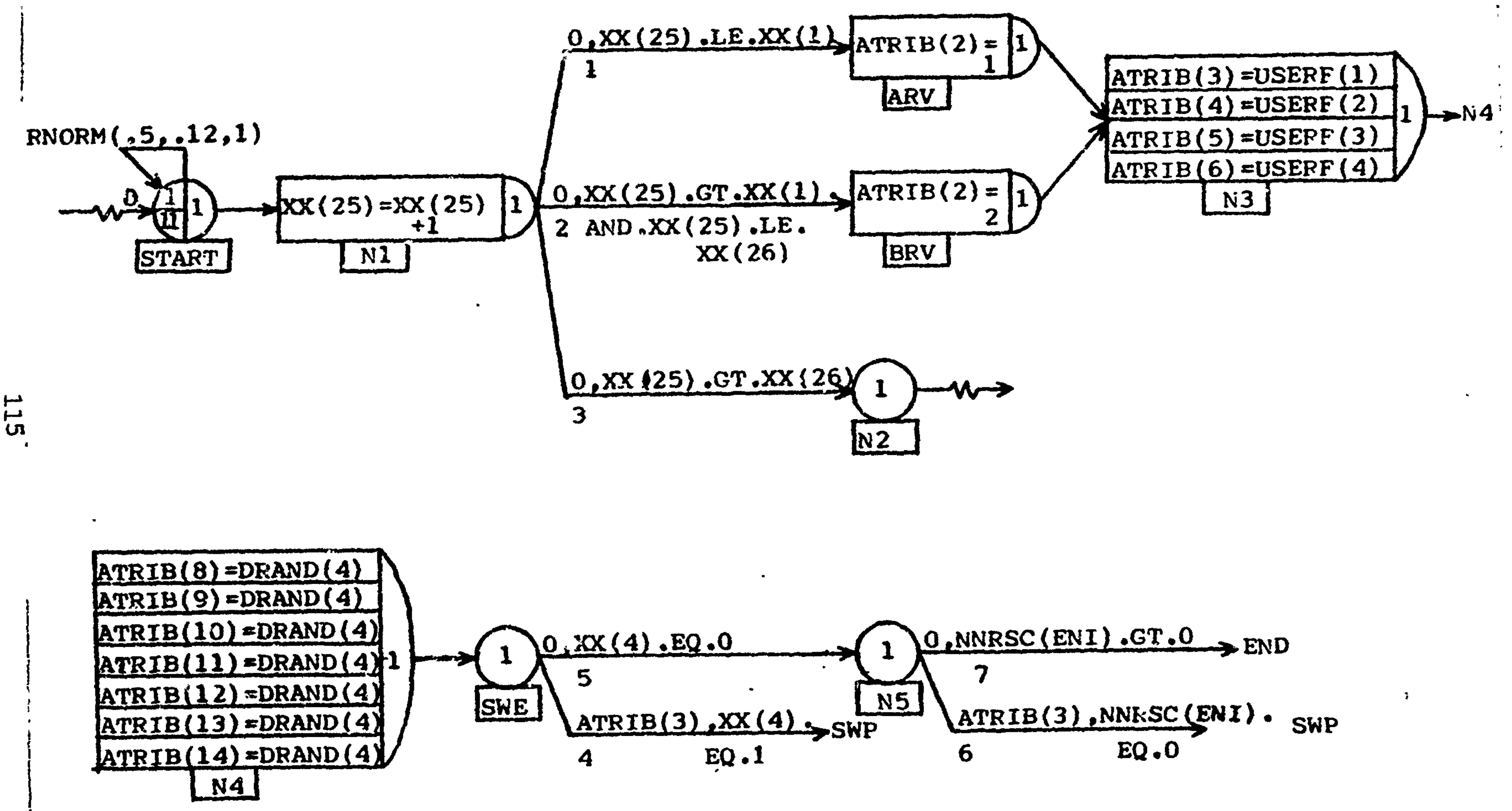
At node N3, each RV is assigned timing information from the FORTRAN subroutines as attributes. At node N4, each RV is subsequently assigned a series of uniform random numbers between zero and one in order to achieve correlated sampling discussed in Chapter IV.

A decision is made at node SWE. If an endo defense is not present, the RV continues on to the point defense switch. If an endo defense is present, the RV continues to node N5 where another decision is made. If there are no endo-interceptors available, the RV continues on to the point defense switch. If endo-interceptors are available, the RV is engaged by the endo defense.

The line of code requiring user change in this segment is

```
START CREATE,RNORM(a,b,1),0,1,c,1;
```

The user enters the mean of the normally distributed RV release time for a. The standard deviation of these release times is entered for b. The user enters the total number of entities, RVs and decoys, to be released for c.



Arriving RVs

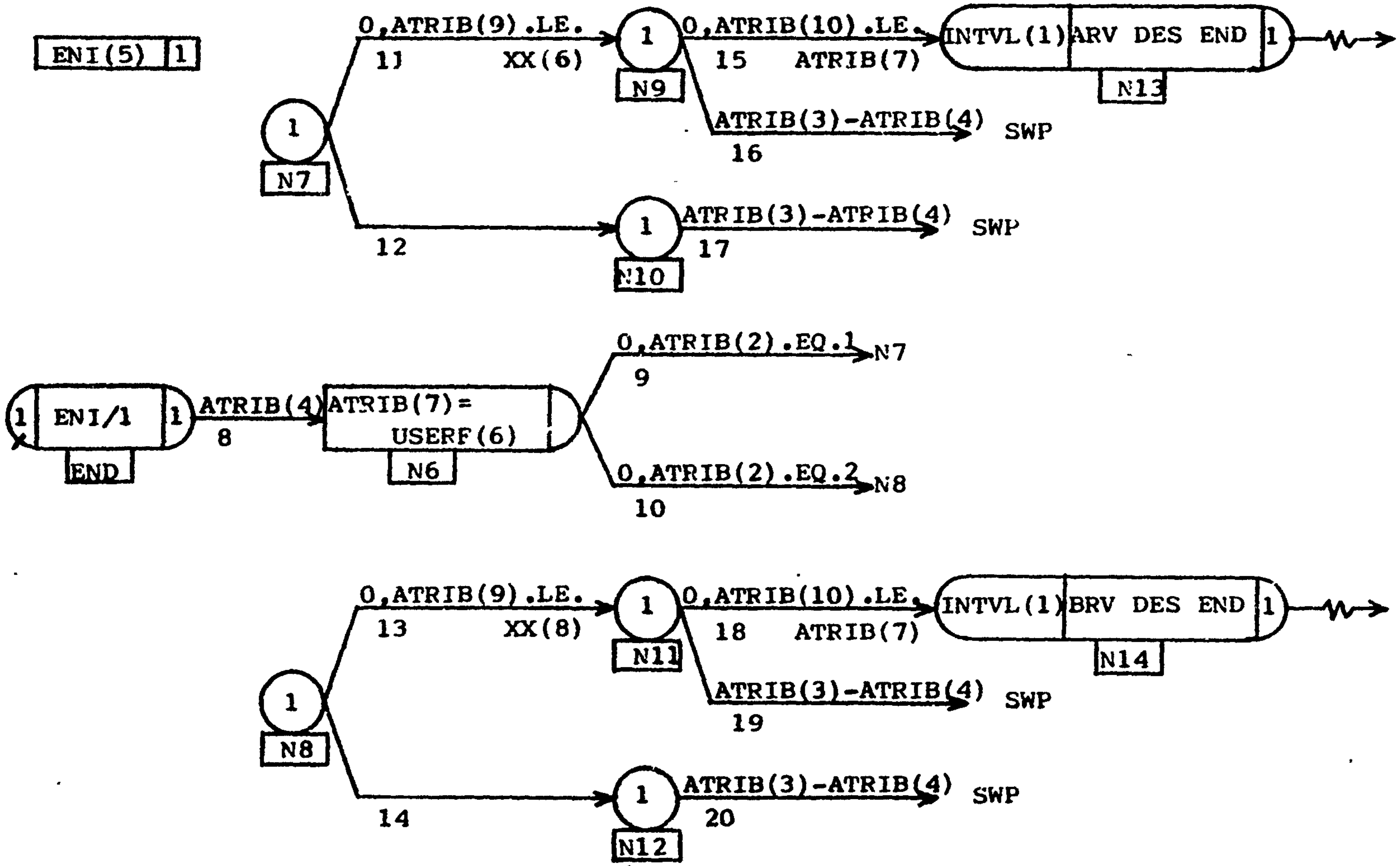
```
;ARRIVING RVS                                                  ;
START CREATE,RNORM(.5,.12,1),0,1,11,1;                         ;STARTING AT TIME 0, GENERATE 11 ENTITIES WHICH ARRIVE
;                                                              ;IAW NORMAL DISTRIBUTION WITH U = .5;   = .12; DENOTE
;                                                              ;THE MARK TIME AS ATTRIBUTE 1.
N1    ASSIGN,XX(25)=XX(25)+1,1;                                ;INCREMENT/COUNT THE ENTITIES.
      ACT/1,0.0,XX(25).LE.XX(1),ARV;                           ;IF ENTITY #  < # ARVS, SEND TO NODE ARV IN 0 TIME.
      ACT/2,0.0,XX(25).GT.XX(1).AND.XX(25).LE.XX(26),BRV;      ;IF # ARVS < ENTITY # < TOTAL # RVS, SEND TO
;                                                              ;NODE BRV IN 0 TIME.
      ACT/3,0.0,XX(25).GT.XX(26),N2;                           ;IF ENTITY # > TOTAL # RVS, SEND TO NODE N2 IN 0 TIME.
  N2    GOON,1;                                                ;NODE FOR DISPOSITION OF DECOYS
      TERM;                                                    ;
ARV   ASSIGN,ATRIB(2)=1,1;                                     ;SET ATTRIBUTE 2 = 1 TO DENOTE ARV AND SEND TO NODE N3.
      ACT,,,N3;                                                ;
BRV   ASSIGN,ATRIB(2)=2,1;                                     ;SET ATTRIBUTE 2 = 2 TO DENOTE BRV AND SEND TO NODE N3
      ACT,,,N3;                                                ;
N3    ASSIGN,ATRIB(3)=USERF(1),                                ;FOR AN RV - SET ATTRIBUTE 3 = TIME TO FLY ENDO FROM USERF (1)
           ATRIB(4)=USERF(2),                                  ;            SET ATTRIBUTE 4 = INTERCEPT TIME IN ENDO FROM USERF (2)
           ATRIB(5)=USERF(3),                                  ;            SET ATTRIBUTE 5 = TIME TO FLY POINT FROM USERF (3)
           ATRIB(6)=USERF(4),1;                                ;            SET ATTRIBUTE 6 = INTERCEPT TIME IN POINT FROM USERF (4)
N4    ASSIGN,ATRIB(8)=DRAND(4),                                ;FOR AN RV - SET ATTRIBUTES 8 THROUGH 14 TO A UNIFORM
            ATRIB(9)=DRAND(4),                                 ;            RANDOM # BETWEEN 0 AND 1 TO ACHIEVE
            ATRIB(10)=DRAND(4),                                ;            CORRELATED SAMPLING; USED LATER IN
            ATRIB(11)=DRAND(4),                                ;            NETWORK TO DETERMINE CEPS OF ENDO AND
            ATRIB(12)=DRAND(4),                                ;            POINT INTERCEPTORS, AND RV, AND DETERMINE
            ATRIB(13)=DRAND(4),                                ;            DISPOSITION OF RV IN ENDO AND POINT
            ATRIB(14)=DRAND(4),1;                              ;            ZONES.
SWE   GOON,1;                                                  ;IF ENDO DEFENSE NOT PRESENT (XX(4) = 1), SEND TO NODE
      ACT/4,ATRIB(3),XX(4).EQ.1,SWP;                           ;SWP IN TIME IT TAKES RV TO FLY ENDO; IF ENDO DEFENSE
      ACT/5,0.0,XX(4).EQ.0,N5;                                 ;PRESENT (XX(4) = 0), SEND TO NODE N5 IN 0 TIME. *
N5    GOON,1;                                                  ;IF # ENDO INTERCEPTORS AVAILABLE = 0, SEND TO NODE SWP
      ACT/6,ATRIB(3),NNRSC(ENI).EQ.0,SWP;                      ;IN TIME IT TAKES RV TO FLY ENDO; IF # ENDO INTERCEPTORS
      ACT/7,0.0,NNRSC(ENI).GT.0,END;                           ;> 1, SEND TO NODE END IN 0 TIME. **
;                                                              ;
                                                               ;* IF XX(4) = 1, RV BYPASSES ENDO DEFENSE ZONE TO POINT DEFENSE SWITCH
                                                               ;** IF # ENDO INTERCEPTORS = 0,RV BYPASSES ENDO DEFENSE ZONE TO POINT
                                                               ;  DEFENSE SWITCH
                                                               ;
```

Arriving RV Code

Endo Defense

As an RV reaches node END, it is assigned an endo-interceptor and continues on to node N6 where the intercept time is reached. At node N6, the RV is assigned a probability of being destroyed by the defense from the FORTRAN subroutines as an attribute. Depending on RV type, the RV then continues to node N7 or N8. The network following these two nodes is the same except for the statistics collected at nodes N13 and N14, respectively. Following N7, the number of ARVs destroyed is collected. Following node N8, the number of BRVs destroyed is collected.

Since the networks are the same, only that following node N7 will be discussed. At node N7, a decision is made as to whether or not the RV is discriminated. If discrimination does not occur, the RV continues on to the point defense switch in the time remaining to fly through the endo defense zone. If the RV is correctly discriminated, a decision is made at node N9 as to whether or not the RV is destroyed. If the RV is destroyed, the number of destroyed RVs of that type is increased by one. If the RV is not destroyed, it continues on to the point defense switch. All of the decisions are based on the outcome of a random number draw.



Endo Defense

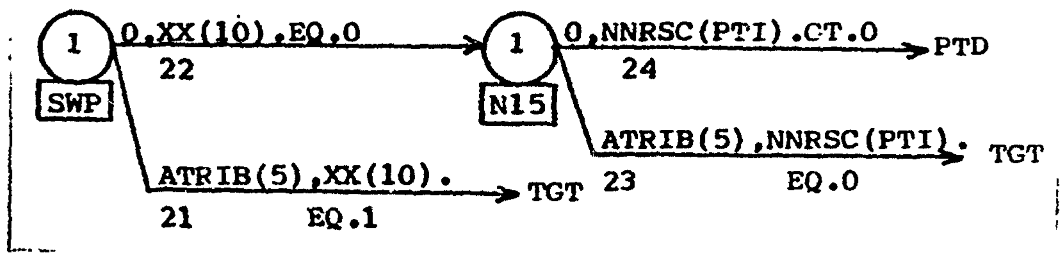
```
;ENDO DEFENSE
END   AWAIT(1),ENI/1,1;
      ACT/8,ATRIB(4),,N6;
N6    ASSIGN,ATRIB(7)=USERF(6),1;
;
      ACT/9,0.0,ATRIB(2).EQ.1,N7;
      ACT/10,0.0,ATRIB(2).EQ.2,N8;
N7    GOON,1;
      ACT/11,0.0,ATRIB(9).LE.XX(6),N9;
      ACT/12,0.0,,N10;
N8    GOON,1;
      ACT/13,0.0,ATRIB(9).LE.XX(8),N11;
      ACT/14,0.0,,N12;
N9    GOON,1;
      ACT/15,0.0,ATRIB(10).LE.ATRIB(7),N13;
      ACT/16,ATRIB(3)-ATRIB(4),,SWP;
N13   COLCT,INTVL(1),ARV DES END,1;
      TERM;
;
N10   GOON,1;
      ACT/17,ATRIB(3)-ATRIB(4),,SWP;
N11   GOON,1;
      ACT/18,0.0,ATRIB(10).LE.ATRIB(7),N14;
      ACT/19,ATRIB(3)-ATRIB(4),,SWP;
N14   COLCT,INTVL(1),BRV DES END,1;
        TERM;
;
N12   GOON,1;
      ACT/20,ATRIB(3)-ATRIB(4),,SWP;
;
```

```
;
;FROM FILE 1, ASSIGN 1 ENDO INTERCEPTOR TO EACH ENTITY
;AND SEND TO NODE N6 IN TIME TO INTERCEPT IN ENDO ZONE
;SET ATTRIBUTE 7 = PROBABILITY THAT ENDO INTERCEPTOR
;KILLS RV FROM USERF (6).
;IF ARV, SEND TO NODE N7 IN 0 TIME.
;IF BRV, SEND TO NODE N8 IN 0 TIME.
;IF ARV AND RANDOM # < PROBABILITY THAT ENDO
;DETECTS THE ARV, SEND TO NODE N9 IN 0 TIME; OTHERWISE
;SEND TO NODE N10 IN 0 TIME.
;IF BRV AND RANDOM # < PROBABILITY THAT ENDO
;DETECTS THE BRV, SEND TO NODE N11 IN 0 TIME; OTHERWISE
;SEND TO NODE N12 IN 0 TIME.
  ;IF ARV DETECTED AND RANDOM # < PROBABILITY OF ENDO
;INTERCEPTOR KILLING THE ARV, SEND TO NODE N13 IN 0
;TIME AND COLLECT INTERVAL STATISTICS ON ATTRIBUTE 1
;FOR DESTROYED ARVS; OTHERWISE ARV SURVIVES
;AND SEND TO NODE SWP IN TIME TO FLY ENDO MINUS
;TIME TO INTERCEPT IN ENDO
;IF ARV NOT DETECTED BY ENDO, SEND TO NODE SWP IN
;TIME TO FLY ENDO MINUS TIME TO INTERCEPT IN ENDO.
;IF BRV DETECTED AND RANDOM # < PROBABILITY OF ENDO
;INTERCEPTOR KILLING THE BRV, SEND TO NODE N14 IN 0
;TIME AND COLLECT INTERVAL STATISTICS ON ATTRIBUTE 1
;FOR DESTROYED BRVS; OTHERWISE BRV SURVIVES AND
;SEND TO NODE SWP IN TIME TO FLY ENDO MINUS
;TIME TO INTERCEPT IN ENDO.
;IF BRV NOT DETECTED BY ENDO, SEND TO NODE SWP IN
;TIME TO FLY ENDO MINUS TIME TO INTERCEPT IN ENDO.
;
```

Endo Defense Code

Point Defense Switch

As an RV reaches node SWP, a decision is made as to whether or not a point defense exists. If the defense does not exist, the RV continues on to the target. If a defense exists, the RV continues to node N15 where another decision is made. If there are no point interceptors available, the RV continues on to the target. If point interceptors are available, the RV is engaged by the point defense.



Point Defense Switch

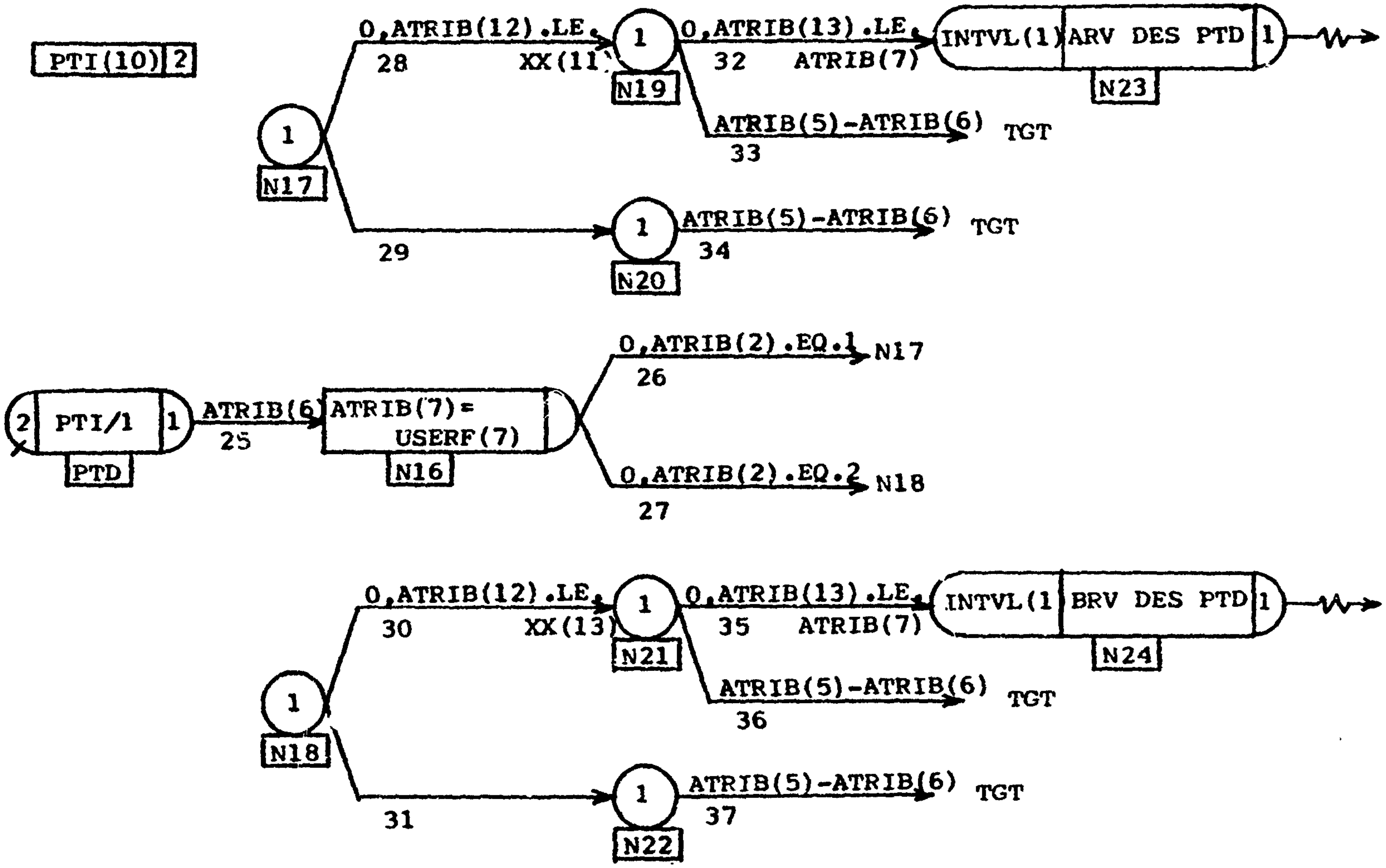
```
;POINT DEFENSE SWITCH
SWP   GOON,1;
      ACT/21,ATRIB(5),XX(10).EQ.1,TGT;
      ACT/22,0.0,XX(10).EQ.0,N15;
N15   GOON,1;
      ACT/23,ATRIB(5),NNRSC(PTI).EQ.0,TGT;
      ACT/24,0.0,NNRSC(PTI).GT.0,PTD;
;
```

```
;
;IF POINT DEFENSE NOT PRESENT (XX(10) = 1),SEND TO NODE
;TGT IN TIME IT TAKES RV TO FLY POINT; IF POINT DEFENSE
;PRESENT (XX(10) = 0),SEND TO NODE N15 IN 0 TIME. *
;IF # POINT INTERCEPTORS AVAILABLE = 0, SEND TO NODE TGT
;IN TIME IT TAKES RV TO FLY POINT; IF # POINT INTERCEPTORS
;> 0, SEND TO NODE PTD IN 0 TIME. **
;
;*  IF XX(10) = 1, RV BYPASSES POINT DEFENSE ZONE TO TARGET.
;** IF # POINT INTERCEPTORS = 0, RV BYPASSES POINT ZONE TO TARGET.
;
```

Point Defense Switch Code

Point Defense

The endo defense discussion applies here. The only differences are that point interceptors are assigned, attribute values differ, and different FORTRAN subroutines are called. The network logic and flow and the decisions are the same.



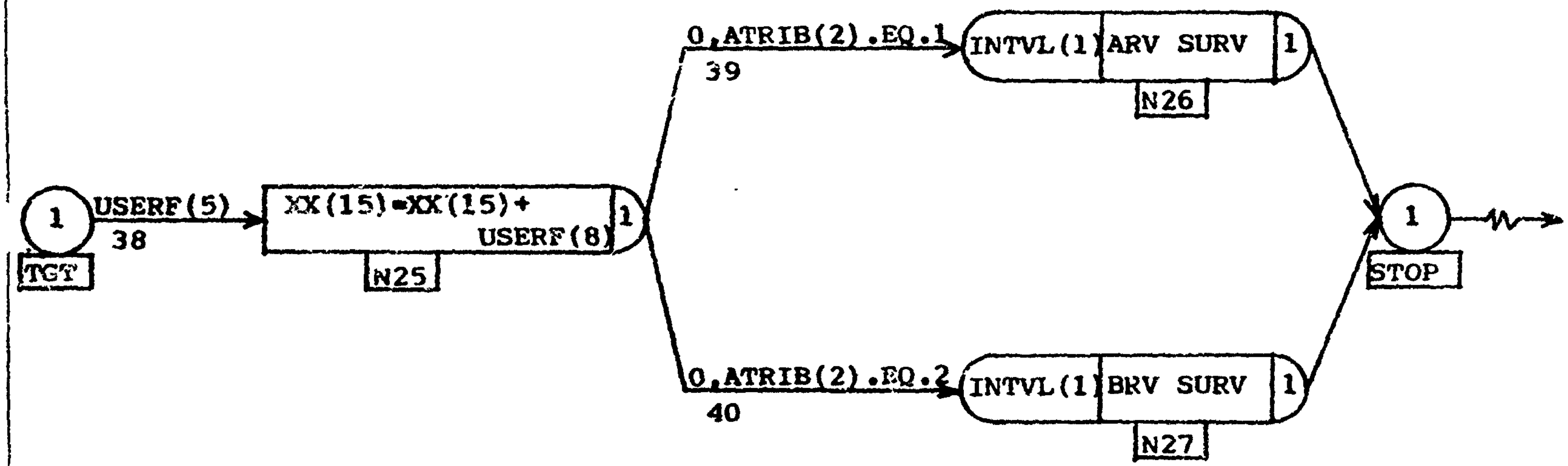
Point Defense

```
      ;POINT DEFENSE                                    ;
PTD    AWAIT(2),PTI/1,1;                                ;FROM FILE 2, ASSIGN 1 POINT INTERCEPTOR TO EACH ENTITY
       ACT/25,ATRIB(6),,N16;                            ;AND SEND TO NODE N16 IN TIME TO INTERCEPT IN POINT ZONE.
N16    ASSIGN,ATRIB(7)=USERF(7),1;                      ;SET ATTRIBUTE 7 = PROBABILITY THAT POINT INTERCEPTOR
;                                                       ;KILLS RV FROM USERF (7).
         ACT/26,Ø.Ø,ATRIB(2).EQ.1,N17;                  ;IF ARV, SEND TO NODE N17 IN Ø TIME.
       ACT/27,Ø.Ø,ATRIB(2).EQ.2,N18;                    ;IF BRV, SEND TO NODE N18 IN Ø TIME.
N17    GOON,1;                                          ;IF ARV AND RANDOM # < PROBABILITY THAT POINT DETECTS
       ACT/28,Ø.Ø,ATRIB(12).LE.XX(11),N19;              ;THE ARV, SEND TO NODE N19 IN Ø TIME; OTHERWISE SEND
       ACT/29,Ø.Ø,,N2Ø;                                 ;TO NODE N2Ø IN Ø TIME.
N18    GOON,1;                                          ;IF BRV AND RANDOM # < PROBABILITY THAT POINT DETECTS
       ACT/3Ø,Ø.Ø,ATRIB(12).LE.XX(13),N21;              ;THE BRV, SEND TO NODE N21 IN Ø TIME; OTHERWISE SEND
       ACT/31,Ø.Ø,,N22;                                 ;TO NODE N22 IN Ø TIME.
N19    GOON,1;                                          ;IF ARV DETECTED AND RANDOM # < PROBABILITY OF POINT
       ACT/32,Ø.Ø,ATRIB(13).LE.ATRIB(7),N23;            ;INTERCEPTOR KILLING THE ARV, SEND TO NODE N23 IN Ø
       ACT/33,ATRIB(5)-ATRIB(6),,TGT;                   ;TIME AND COLLECT INTERVAL STATISTICS ON ATTRIBUTE 1
N23    COLCT,INTVL(1),ARV DES PTD,1;                    ;FOR DESTROYED ARVS; OTHERWISE ARV SURVIVES
       TERM;                                            ;AND SEND TO NODE TGT IN TIME TO FLY POINT MINUS
;                                                       ;TIME TO INTERCEPT IN POINT.
N2Ø    GOON,1;                                          ;IF ARV NOT DETECTED BY POINT, SEND TO NODE TGT IN
       ACT/34,ATRIB(5)-ATRIB(6),,TGT;                   ;TIME TO FLY POINT MINUS TIME TO INTERCEPT IN POINT.
N21    GOON,1;                                          ;IF BRV DETECTED AND RANDOM # < PROBABILITY OF POINT
       ACT/35,Ø.Ø,ATRIB(13).LE.ATRIB(7),N24;            ;INTERCEPTOR KILLING THE BRV, SEND TO NODE N24 IN Ø
       ACT/36,ATRIB(5)-ATRIB(6),,TGT;                   ;TIME AND COLLECT INTERVAL STATISTICS ON ATTRIBUTE 1
N24    COLCT,INTVL(1),BRV DES PTD,1;                    ;FOR DESTROYED BRVS; OTHERWISE BRV SURVIVES AND
       TERM;                                            ;SEND TO NODE TGT IN TIME TO FLY POINT MINUS
;                                                       ;TIME TO INTERCEPT IN POINT.
N22    GOON,1;                                          ;IF BRV NOT DETECTED BY POINT, SEND TO NODE TGT IN
       ACT/37,ATRIB(5)-ATRIB(6),,TGT;                   ;TIME TO FLY POINT MINUS TIME TO INTERCEPT IN POINT.
;                                                       ;
```

Point Defense Code

Target Area

As a surviving RV reaches node TGT, the RV continues on to the target in the time it takes to fly the last 10,000 feet to the target. At node N25, the average probability of target area destruction is accumulated and updated as each RV reaches its target. The number of surviving RVs is collected by type. The simulation, one run, is then terminated.


1
TGT
USERF(5)
38
XX(15)=XX(15)+
USERF(8)
1
N25
0,ATRIB(2).EQ.1
39
INTVL(1)
ARV SURV
1
N26
0,ATRIB(2).EQ.2
40
INTVL(1)
BRV SURV
1
N27
1
STOP

Target Area

```
;TARGET AREA
TGT    GOON,1;
       ACT/38,USERF(5),,N25;
N25    ASSIGN,XX(15)=XX(15)+USERF(8),1;
;
;
       ACT/39,0.0,ATRIB(2).EQ.1,N26;
       ACT/40,0.0,ATRIB(2).EQ.2,N27;
N26    COLCT,INTVL(1),ARV SURV,1;
       ACT,,,STOP;
N27    COLCT,INTVL(1),BRV SURV,1;
       ACT,,,STOP;
STOP   GOON,1;
       TERM;
       END;
;
```

```
;
;[illegible] RV TO NODE N25 IN TIME TO FLY LAST
;10,000 FT TO TARGET FROM USERF (5).
;STARTING FROM XX(15) = 0, ADD THE PROBABILITY THAT AN
;RV DESTROYS ITS TARGET FROM USERF (8) TO OBTAIN
;THE TOTAL PROBABILITY OF TARGET AREA DESTRUCTION.
;IF ARV, SEND TO NODE N26 IN 0 TIME TO COLLECT
;INTERVAL STATISTICS ON ATTRIBUTE 1 FOR SURVIVING
;ARVS THEN SEND TO NODE STOP IN 0 TIME;
;IF BRV, SEND TO NODE N27 IN 0 TIME TO COLLECT
;INTERVAL STATISTICS ON ATTRIBUTE 1 FOR SURVIVING
;BRVS THEN SEND TO NODE STOP IN 0 TIME.
;
;
;
;
```

Target Area Code

SLAM Support Code

There is no network structure for the SLAM support code. The first requirements for a simulation run are those instructions normally required by the CDC for a job, the job control list (JCL), the first six lines of the following code. The fourth, fifth, and sixth lines reflect differences from a general case for program input that are required for the specific case of this simulation model. BAMRV is the name of the permanent file containing the compiled FORTRAN subroutines. The permanent file identification is BUZZ. The program, SLAMPROC, is a procedure file, written in CDC control language, that contains instructions for attaching and processing the SLAM support program. The sixth line is the instruction for the computer to begin the SLAM procedure file, using an externally compiled program, BAMRV, as an additional input, and having a print line limit of 10,000 lines.

The block of code following the JCL begins the SLAM portion of the code. At the end of the first line of code in this block is a number indicating the number of runs the user wishes to make. The resource statements, the last two lines of code in this block, reflect the number of endo-interceptors and point interceptors that make up the defense. The remaining network code, in the order discussed in the previous five sections, would follow this block of code. The lines of code requiring user change in this block are as follows

```
GEN,WILCRIT,THESIS,18/15/1981,a;
     RESOURCE/ENI(b),1,
     RESOURCE/PTI(c),2;
```

In the first line, the user enters the number of runs desired for a. In the second line, b indicates the desired number of endo-interceptors. The c in the third line indicates the number of point interceptors desired.

The last block of code is the initialization statements that set the values of the global variables in the model. The use of global variables provides extensive flexibility that permits the simulation of both widely divergent RV/BMD systems and minor variations on a single system. As a result of the global variables, the structure of the system network can be altered without changing the actual programming of the network. Global variables are used to open and close pathways, activate and deactivate defenses, and define the capabilities and vulnerabilities of the system. Furthermore, they are used to reflect variations in the system parameters between simulation runs. The user must set all of these global variables to specific values prior to exercising the model. The access to classified information is critical in setting appropriate values for these variables.

```
CLC,CM122000,T40,IO100. (810485,WILLIAMS,BOX4583      ;JOB CONTROL CARDS
ATTACH,PROCFIL,ID=A810171,SN=ASDAD.                   ;
BEGIN,NOSFILE.                                        ;
GET,BAMRV,ID=BUZZ.                                    ;
ATTACH,PROCFIL,SLAMPROC,ID=AFIT.                      ;
BEGIN,SLAM,,M=BAMRV,PL=10000.                         ;
```

```
GEN WILCRIT,THESIS,10/15/1981,18;      ;MAKE 18 RUNS
LIMITS,2,14,20;                        ;2 FILES, 14 ATTRIBUTES PER ENTITY, 20 CONCURRENT
;                                      ;ENTITIES IN FILES (MAX)
TIMST,XX(15),PROB TGT DES;             ;COLLECT TIME PERSISTENT STATISTICS ON XX(15)
NETWORK;                               ;
      RESOURCE/ENI(5),1;               ;5 ENDO INTERCEPTORS IN FILE 1
      RESOURCE/PTI(10),2;              ;10 POINT INTERCEPTORS IN FILE 2
;                                      ;
```

```
 ;INITIALIZE GLOBAL VARIABLES                                          ;
INTLC,XX(1)=3,XX(2)=24,XX(3)=24,XX(4)=0,XX(5)=1,XX(6)=.7;             ;8 INITIALIZE CARDS TO INITIALIZE
INTLC,XX(7)=22000.0,XX(8)=.7,XX(9)=8,XX(10)=0,XX(11)=.5;              ;GLOBAL VARIABLES TO SPECIFIC VALUES
INTLC,XX(12)=1E13,XX(13)=.7,XX(14)=1E15;                              ;
INTLC,XX(15)=0,XX(16)=0,XX(17)=1000,XX(18)=3000,XX(19)=20;            ;
INTLC,XX(20)=1000,XX(21)=150,XX(22)=200,XX(23)=350;                   ;
INTLC,XX(24)=600,XX(25)=0,XX(26)=10,XX(27)=70,XX(28)=100;             ;
INTLC,XX(29)=1E12,XX(30)=1E14;                                        ;
INTLC,XX(31)=20,XX(32)=50,XX(33)=2000,XX(34)=6000;                    ;
INITIALIZE,0.0,60.0;                                                  ;START AT TIME 0 FOR EACH RUN
;                                                                     ;AND RUN FOR 60 TIME UNITS
;
```

SLAM Support Code

Annotated FORTRAN User Function Code

```
      FUNCTION USERF(IFN)
      COMMON/SCOM1/ATRIB(100),DD(100),DDL(100),DTNOW,II,MFA,MSTOP,
     +  NCLNR,NCRDR,NPRNT,NNRUN,NNSET,NTAPE,SS(100),SSL(100),
     +  TNEXT,TNOW,XX(100)
      COMMON/RW/X,HNU,A1,C1,C2,HNUT,AIRDEN,TE,TP
      REAL HNU(10),A1(32),C1(32),C2(32),HNUT(32),MUTRO,MFP,
     +   AIRDEN(87),INTALE,INTALP
C
C     VARIABLE KEY
C        X = REENTRY ANGLE OF AN RV IN DEGREES
C        HYP = SLANT RANGE THAT RV FLIES THROUGH ENDO OR POINT
C              DEFENSE ZONES IN FEET
C        TE = TIME FOR RV TO FLY THROUGH ENDO ZONE IN SECONDS
C        UE = MEAN TIME OF ABM INTERCEPT IN ENDO ZONE IN SECONDS
C        SDE = STANDARD DEVIATION OF TIME OF ABM INTERCEPT IN
C              ENDO ZONE IN SECONDS
C        RN = NORMAL RANDOM VARIATE
C        TP = TIME FOR RV TO FLY THROUGH POINT ZONE IN SECONDS
C        UP = MEAN TIME OF ABM INTERCEPT IN POINT ZONE IN SECONDS
C        SDP = STANDARD DEVIATION OF TIME OF ABM INTERCEPT IN
C              POINT ZONE IN SECONDS
C        YIELD = YIELD OF AN ABM OR RV IN KILOTONS
C        TEMP = TEMPERATURE OF X-RAYS IN KEV
C        SR = MISS DISTANCE OF AN ABM OR RV IN FEET OR KILOMETERS
C        DNSS = SURE SAFE NEUTRON INTENSITY IN NEUTRONS/CM2
C        DNSK = SURE KILL NEUTRON INTENSITY IN NEUTRONS/CM2
C        DXSS = SURE SAFE X-RAY INTENSITY IN CALORIES/CM2
C        DXSK = SURE KILL X-RAY INTENSITY IN CALORIES/CM2
C        R = MISS DISTANCE IN CENTIMETERS
C        INTALE = ALTITUDE OF ENDO INTERCEPT IN FEET OR KILOMETERS
C        INTALP = ALTITUDE OF POINT INTERCEPT IN FEET OR KILOMETERS
C        L = ALTITUDE OF ENDO OR POINT INTERCEPT TO NEAREST KILOMETER
C        PMI = MASS INTEGRAL IN GM/CM2 (AIR DENSITY TIMES SLANT RANGE)
C        PIR2F = NEUTRON FLUENCE AT A PARTICULAR RANGE SR AND ALTITUDE L
C        F = NEUTRON FLUENCE ON RV
C        YIELD1 = YIELD OF ENDO INTERCEPTOR IN CALORIES
C        SUMF = TOTAL X-RAY FREE FIELD FLUENCE ON RV
C        HNU1 = NON-NORMALIZED ENERGY OF X-RAYS IN A PARTICULAR GROUP
C        MUTRO = X-RAY ATTENUATION COEFFICIENT FOR AIR IN CM2/GM
C        MFP = MEAN FREE PATHS (MASS INTEGRAL TIMES X-RAY ATTENUATION
C              COEFFICIENT FOR AIR)
C        BUF = X-RAY BUILD UP FACTOR
C        FFFG = FREE FIELD X-RAY FLUENCE FOR A PARTICULAR GROUP
C        FFFT = TOTAL X-RAY FLUENCE ON RV
C        RNSK = RANGE OF NEUTRON SURE KILL IN KILOMETERS OR CENTIMETERS
C        RNSS = RANGE OF NEUTRON SURE SAFE IN KILOMETERS OR CENTIMETERS
C        DNA = ALPHA VALUE FOR NEUTRON CALCULATIONS
C        DNB = BETA VALUE FOR NEUTRON CALCULATIONS
C        WR OR WR1 = WEAPON RADIUS FOR NEUTRONS
C        PROBA OR PROB1A = POWER OF EXPONENT IN SINGLE SHOT PROBABILITY
```

```
C                         OF NEUTRON KILL CALCULATIONS
C        PROB OR PROB1 = SINGLE SHOT PROBABILITY OF KILL FOR NEUTRONS
C        RXSK = RANGE OF X-RAY SURE KILL IN KILOMETERS OR CENTIMETERS
C        RXSS = RANGE OF X-RAY SURE SAFE IN KILOMETERS OR CENTIMETERS
C        DXA = ALPHA VALUE FOR X-RAY CALCULATIONS
C        DXB = BETA VALUE FOR X-RAY CALCULATIONS
C        WR2 = WEAPON RADIUS FOR X-RAYS
C        PROB2A = POWER OF EXPONENT IN SINGLE SHOT PROBABILITY OF
C                 X-RAY KILL CALCULATIONS
C        PROB2 = SINGLE SHOT PROBABILITY OF KILL FOR X-RAYS
C        PS = SINGLE SHOT PROBABILITY OF SURVIVAL OF RV IN ENDO ZONE
C        DPSS = SURE SAFE OVERPRESSURE FOR TARGET
C        DPSK = SURE KILL OVERPRESSURE FOR TARGET
C        DPA = ALPHA VALUE FOR OVERPRESSURE CALCULATIONS
C        DPB = BETA VALUE FOR OVERPRESSURE CALCULATIONS
C        SSR = MISS DISTANCE OF RV SCALED TO 1 KILOTON IN FEET
C        RR1 = SSR
C        STMRM = SCALED MISS DISTANCE OF RV IN METERS
C        DP= OVERPRESSURE ON TARGET
C        ANGTT, P9, P0 = USED IN EMPIRICAL FIT FOR OVERPRESSURE CALCULATIONS
C        R1 = SCALED MISS DISTANCE OF RV IN KILOMETERS
C        DP1 = ALTERNATE OVERPRESSURE FIGURE ON TARGET
C        Z = PROBABILITY OF DAMAGE TO TARGET
C        ZZ = ALTERNATE PROBABILITY OF DAMAGE FIGURE TO TARGET
C        PROB = AVERAGE TARGET DESTRUCTION TO TARGET AREA
C
```

```
C     INPUT DATA
C
C     MIDPOINTS OF 10 EQUAL ENERGY GROUPS OF PLANCK'S SPECTRUM
      DATA HNU/.77,1.82,2.34,2.81,3.27,3.76,4.32,5.00,5.97,8.28/
C
C     THE NEXT FOUR DATA GROUPS ARE ARRAYS OF KALANSKY'S CONSTANTS
C     TO COMPUTE BUILD UP FACTOR
      DATA HNUT/12.0,14.0,16.0,18.0,20.0,
     +   22.0,24.0,26.0,28.0,30.0,
     +   32.0,34.0,36.0,38.0,40.0,
     +   45.0,50.0,55.0,60.0,70.0,
     +   80.0,100.0,120.0,150.0,200.0,
     +   250.0,300.0,350.0,400.0,500.0,
     +   600.0,750.0/
C
      DATA A1/-.227,-.370,-.323,-.634,-1.072,
     +   -1.048,-1.740,-2.673,-2.664,-6.038,
     +   -8.805,-8.504,-75.830,-20.030,-16.940,
     +   14.59,11.31,109.2,-11.05,-114.1,
     +   -113.1,-10.93,-8.153,13.14,-88.92,
     +   -6.308,19.89,72.37,-6.063,16.29,
     +   -57.58,-17.2/
C
      DATA C1/-.4,-.4,-.68,-.46,-.36,
     +   -.48,-.34,-.26,-.3,-.14,
     +   -.1,-.1,0.0,-.02,-.02,
     +   .12,.16,.12,0.0,.14,
     +   .16,.06,.02,.26,.18,
     +   0.0,.2,.16,0.0,.16,
     +   .1,.06/
C
      DATA C2/0.0,0.0,.02,.02,.02,
     +   .04,.04,.04,.06,.04,
     +   .04,.06,.02,.06,.08,
     +   -.02,-.04,.1,.2,.16,
     +   .18,.26,.28,.1,.2,
     +   .26,.12,.14,.22,.08,
     +   .12,.12/
C
C     AIR DENSITY IN KG/M3 FOR ALTITUDE FROM 0 TO 86 KM
      DATA AIRDEN/1.225,1.1117,1.0066,.90925,.81935,.73643,.66011,
     +    .59002,.52579,.46706,.41351,.36480, 1194,.26660,
     +    .22786,.19476,.16647,.14230,.12165  .040C,.08891,
     +    .075715,.06451,.055006,.046938,.04 .84,.034257,.029298,
     +    .025076,.021478,.018410,.015792,.013555,.011573,
     +    .0098874,.0084634,.0072579,.0062355,.0053666,.0046268,
     +    .0039957,.0034564,.0029948,.0025989,.0022589,.0019663,
     +    .0017142,.0014965,.0013167,.0011628,.0010269,.0009069,
     +    .00080562,.00071791,.00063901,.00056810,.00050445,
     +    .00044738,.00039627,.00035054,.00030968,.00027321,
```

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     +    .00024071,.00021178,.00018605,.00016321,.00014296,
     +    .00012503,.00010917,.000095171,.000082829,.000071966,
     +    .000062374,.000053824,.000046386,.000039921,.000034311,
     +    .000029448,.000025239,.000021600,.000018458,.000015750,
     +    .000013418,.000011414,.0000096940,.0000082196,0.0/
C
```

```
C     DETERMINE RV REENTRY ANGLE BY RV TYPE
      IF(ATRIB(2).EQ.1)X=XX(2)
      IF(ATRIB(2).GT.1)X=XX(3)
      GO TO (1,2,3,4,5,6,7,8),IFN
C
C     USER FUNCTIONS ONE THROUGH FIVE
C
C*********************************************************************
C     USER FUNCTION 1 - CALCULATE TIME TO FLY THROUGH ENDO DEFENSE ZONE
    1 HYP = 80000/SIND(X)
      TE  = HYP/XX(7)
      USERF = TE
      RETURN
C
C*********************************************************************
C     USER FUNCTION 2 - CALCULATE TIME OF INTERCEPT IN ENDO DEFENSE ZONE
    2 UE = (TE-.1)/2
      SDE = (TE - UE)/3
      RN = RNORM(UE,SDE,2)
      IF(RN.LT.0.1)USERF=.1
      IF(RN.GT.TE)USERF=TE
      IF((RN.GE.0.1).AND.(RN.LE.TE))USERF=RN
      RETURN
C
C*********************************************************************
C     USER FUNCTION 3 - CALCULATE TIME TO FLY THROUGH POINT DEFENSE ZONE
    3 HYP  =  60000/SIND(X)
      TP   =  HYP/XX(7)
      USERF = TP
      RETURN
C
C*********************************************************************
C     USER FUNCTION 4 - CALCULATE TIME OF INTERCEPT IN POINT DEFENSE ZONE
    4 UP  =  (TP - .1)/2
      SDP =  (TP - UP)/3
      RN  =  RNORM(UP,SDP,3)
      IF(RN.LT.0.1)USERF=.1
      IF(RN.GT.TP)USERF=TP
      IF((RN.GE.0.1).AND.(RN.LE.TP))USERF=RN
      RETURN
C
C*********************************************************************
C     USER FUNCTION 5 - CALCULATE TIME TO FLY LAST 10,000 FEET TO TARGET
    5 HYP  =  10000/SIND(X)
      USERF = HYP/XX(7)
      RETURN
C
```

```
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C     USER FUNCTION 6 - CALCULATE SINGLE SHOT KILL PROBABILITY OF
 C                        ENDO INTERCEPTOR
  6   YIELD = XX(17)
      TEMP = XX(9)
      RN=ATRIB(8)
C     CALCULATE MISS DISTANCE
      SR=SQRT(XX(18)**2*(LOG(1-RN)/(-.693)))
      PRINT *,'   RANGE = ',SR
      IF(ATRIB(2).EQ.1)THEN
C         SET X-RAY AND NEUTRON KILL LEVELS FOR ARV
          DNSS = XX(12)
          DNSK = XX(14)
          DXSS = XX(27)
          DXSK = XX(28)
      ELSE
C         SET X-RAY AND NEUTRON KILL LEVELS FOR BRV
          DNSS = XX(29)
          DNSK = XX(30)
          DXSS = XX(31)
          DXSK = XX(32)
      ENDIF
 C      CALCULATE MISS DISTANCE IN KM
      SR  =  SR * .0003048
C     CALCULATE MISS DISTANCE IN CM
      R   =  SR  * 10. ** 5.
C     CALCULATE ALTITUDE OF ENDO INTERCEPT TO NEAREST KM
      INTALE = 150000. - ATRIB(4) * XX(7) * SIND(X)
      INTALE = INTALE * .0003048
      L     = NINT(INTALE) + 1
C     CALCULATE MASS INTEGRAL
      PMI = AIRDEN(L) * SR * 10 ** 2
C     CALCULATE NEUTRON FLUENCE ON RV
      PIR2F = EXP(-6.775 + .005269 * PMI - .000005346
     +    * PMI ** 2 - .00021468 * PMI ** 1.5 -
     +    3.8214 * PMI ** .5 + 10.875 * PMI **
     +    (1./3.) - 1.3975 * LOG(PMI))
      F   =  (3.16E23 * YIELD * PIR2F)/(4*3.1416*R**2)
C
C     CALCULATE X-RAY FLUENCE ON RV
C
C     CALCULATE YIELD IN CALORIES
      YIELD1  =  YIELD * 1E12
      SUMF    =  0.
      DO 100 I = 1,10
C           CALCULATE ENERGY OF X-RAYS IN GROUP I
            HNU1 = TEMP * HNU(I)
C           CALCULATE X-RAY ATTENUATION COEFFICIENT FOR AIR
            MUTRO = -.001354 + 19.7564 / HNU1 - 461.763
     +      / HNU1 ** 2. + 6680.02 / HNU1 ** 3.
```

```
     +     - 3497.36 / HNU1 ** 4. + 907.358 / HNU1 ** 5.
C     LOCATE KALANSKY'S CONSTANTS
      MFP    =  PMI * MUTRO
            IF(HNU1.LT.12.)THEN
               BUF = 1
               GO TO 20
            ELSE
                DO 200 J = 1,32
              IF(HNUT(J).GT.HNU1)THEN
                   IF(HNUT(J)-HNU1.GT.HNU1-HNUT(J-1))THEN
                       K  = J - 1
                   ELSE
                       K = J
             ENDIF
             GO TO 10
             ENDIF
 200  CONTINUE
      ENDIF
C     CALCUALTE BUILD UP FACTOR
  10  A2 = 1 - A1(K)
      BUF = A1(K) * EXP(C1(K) * MFP) + A2 * EXP (C2
     +    (K) * MFP)
C     CALCULATE ENERGY IN GROUP I
  20  FFFG = .1 * BUF * EXP(-MUTRO * PM
      SUMF = SUMF + FFFG
 100  CONTINUE
C     CALCULATE TOTAL X-RAY FLUENCE ON RV
      FFFT = .8 * YIELD1 * (SUMF/(4 * 3.1416 * R ** 2.))
      PRINT *,'   F = ',F,'   PIR2F = ',PIR2F
      PRINT *,'   FFFT = ',FFFT,'   SUMF =',SUMF
C
C     ITERATE TO FIND NEUTRON SURE KILL RANGE
      DO 500 JJ=1,100
          PMI = AIRDEN(L)*JJ*10**2
          PIR2F=EXP(-6.775+.005269*PMI-.0000005346
     +        *PMI**2-.00021468*PMI**1.5-
     +        3.8214*PMI**.5+10.875*PMI**
     +        (1./3.)-1.3975*LOG(PMI))
          F=3.16E23*YIELD*PIR2F/(4*3.1416*(JJ*10**5)**2)
          IF(F.LE.DNSK)THEN
              RNSK = JJ
      PRINT *,'   F = ',F,'   PIR2F = ',PIR2F,'   RNSK = ',RNSK
              GO TO 900
          ENDIF
500   CONTINUE
900   RNSK=RNSK*10**5
C
C     ITERATE TO FIND NEUTRON SURE SAFE RANGE
      DO 501 KK=1,100
          PMI=AIRDEN(L)*KK*10**2
```

```
      PIR2F=EXP(-6.775+.005269*PMI-.000005346
     +    *PMI**2-.00021463*PMI**1.5-
     +    3.3214*PMI**.5+10.875*PMI**
     +    (1./3.)-1.3975*LOG(PMI))
      F = 3.16E23*YIELD*PIR2F/(4*3.1416*(KK*10**5)**2)
      IF(F.LE.DNSS)THEN
          RNSS=KK
   PRINT *,'  F = ',F,'   PIR2F = ',PIR2F,'   RNSS = ',RNSS
          GO TO 901
      ENDIF
501   CONTINUE
901   RNSS = RNSS * 10 **5
C
C     CALCULATE PROBABILITY OF NEUTRON KILL
      DNA  =  .5 * LOG (RNSK * RNSS)
      DNB  =  (.5/2.054)*LOG(RNSK/RNSS)
C     CALCULATE WEAPON RADIUS FOR NEUTRONS
      WR1  =  EXP(DNA + DNB ** 2.)
      PRINT *,'  DNA = ',DNA,'  DNB = ',DNB,'  WR1 = ',WR1
C     CALCULATE SINGLE SHOT PROBABILITY OF NUETRON KILL
      PROB1A = -.693*(WR1/(XX(10)*30.48))**2.
      IF(ABS(PROB1A).GT.23)THEN
         PROB1 = 1.
         ELSE
         PROB1 = 1-EXP(PROB1A)
      ENDIF
C
C     ITERATE TO FIND X-RAY SURE KILL RANGE
      DO 502 LL=1,100
          RR = FLOAT(LL)* .2
         PMI = AIRDEN(L)*RR*10**2.
         SUMF = 0.
         DO 503 LLI = 1,10
            HNU1 = TEMP * HNU(LLI)
            MUTRO = -.001354+19.7564/HNU1-461.763
     +       /HNU1**2.+6680.02/HNU1**3.
     +       -3497.36/HNU1**4.+907.358/HNU1**5.
            MFP  = PMI * MUTRO
            IF(HNU1.LT.12.)THEN
               BUF = 1.
               GO TO 902
            ELSE
               DO 504 MM = 1,32
                  IF(HNUT(MM).GT.HNU1)THEN
                     IF(HNUT(MM)-HNU1.GT.HNU1-HNUT(MM-1))THEN
                        K = MM - 1
                     ELSE
                        K = MM
                     ENDIF
                  GO TO 903
```

```
                   ENDIF
504             CONTINUE
             ENDIF
903          A2 = 1-A1(K)
             BUF = A1(K)*EXP(C1(K)*MFP)+A2*EXP(C2
     +          (K)*MFP)
902          FFFC = .1*BUF*EXP(-MUTRO*PMI)
             SUMF = SUMF + FFFG
503       CONTINUE
          FFFT = .8*YIELD1*SUMF/(4*3.1416*(RR*10**5.)**2.)
          IF(FFFT.LE.DXSK)THEN
             RXSK = RR
      PRINT *,'   FFFT = ',FFFT,'   SUMF = ',SUMF
      PRINT *,'   RXSK = ',RXSK
             GO TO 904
          ENDIF
502   CONTINUE
904   RXSK=RXSK*10**5
C
C     ITERATE TO FIND X-RAY SURE SAFE RANGE
      DO 505 LL=1,100
          RR=FLOAT(LL)*.2
          PMI = AIRDEN(L)*RR*10**3.
          SUMF = 0.
          DO 506 LLI = 1,10
             HNU1 = TEMP * HNU(LLI)
             MUTRO = -.001354+19.7564/HNU1-461.763
     +         /HNU1**2.+6680.02/HNU1**3.
     +         -3497.36/HNU1**4.+907.358/HNU1**5.
             MFP  = PMI * MUTRO
             IF(HNU1.LT.12.)THEN
                BUF = 1.
                GO TO 905
             ELSE
                DO 507 MM = 1,32
                     IF(HNUT(MM).GT.HNU1)THEN
                         IF(HNUT(MM)-HNU1.GT.HNU1-HNUT(MM-1))THEN
                             K = MM - 1
                         ELSE
                             K = MM
                         ENDIF
                     GO TO 906
                     ENDIF
507             CONTINUE
             ENDIF
906          A2 = 1-A1(K)
             BUF = A1(K)*EXP(C1(K)*MFP)+A2*EXP(C2
     +          (K)*MFP)
905          FFFG = .1*BUF*EXP(-MUTRO*PMI)
             SUMF = SUMF + FFFG
```

```
 596      CONTINUE
        FFFT = .8*YIELD1*SUMF/(4*3.1416*(RR*10**5.)**2.)
        IF(FFFT.LE.DXSS)THEN
           RXSS = RR
      PRINT *,'   FFFT = ',FFFT,'   SUMF = ',SUMF
      PRINT *,'   RXSS = ',RXSS
           GO TO 907
        ENDIF
595   CONTINUE
907   RXSS=RXSS*10**5
 C
C     CALCULATE PROBABILITY OF X-RAY KILL
      DXA   =  .5*LOG(RXSK*RXSS)
      DXB   =  (.5/2.054)*LOG(RXSK/RXSS)
C     CALCULATE WEAPON RADIUS FOR X-RAYS
      WR2   =  EXP(DXA+DXB**2.)
      PRINT *,'   DXA = ',DXA,'   DXB = ',DXB,'   WR2 = ',WR2
C     CALCULATE SINGLE SHOT PROBABILITY OF X-RAY KILL
      PROB2A = -.693*(WR2/(XX(18)*30.48))**2.
      IF(ABS(PROB2A).GT.23.)THEN
         PROB2 = 1.
      ELSE
         PROB2 = 1 - EXP(PROB2A)
      ENDIF
C     CALCULATE SINGLE SHOT PROBABILITY OF RV SURVIVAL
      PS =  (1-PROB1)*(1-PROB2)
C     CALCULATE SINGLE SHOT PROBABILITY OF RV KILL BY ENDO INTERCEPTOR
      USERF = 1 - PS
      RETURN
C
```

```
C+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
C     USER FUNCTION 7 - CALCULATE SINGLE SHOT KILL PROBABILITY OF
C                       POINT INTERCEPTOR
  7   YIELD  = XX(19)
      RN=ATRIB(11)
C     CALCULATE MISS DISTANCE
      SR=SQRT(XX(20)**2*(LOG(1-RN)/(-.693)))
      PRINT *,'   RANGE = ',SR
      IF(ATRIB(2).EQ.1)THEN
C        SET NEUTRON KILL LEVELS FOR ARV
         DNSS  =  XX(12)
         DNSK  =  XX(14)
      ELSE
C        SET NEUTRON KILL LEVELS FOR BRV
         DNSS  =  XX(29)
         DNSK  =  XX(30)
      ENDIF
C     CALCULATE MISS DISTANCE IN KM
      SR   =  SR * .0003048
C     CALCULATE MISS DISTANCE IN CM
      R    =  SR * 10 ** 5
C     CALCULATE ALTITUDE OF POINT INTERCEPT TO NEAREST KM
      INTALP = 70000. - ATRIB(6) * XX(7) * SIND(X)
      INTALP = INTALP * .0003048
      M    = NINT(INTALP) + 1
C     CALCULATE MASS INTEGRAL
      PMI = AIRDEN(M) * SR * 10 ** 2
C     CALCULATE NEUTRON FLUENCE ON RV
      PIR2F = EXP(-6.775 + .005269 * PMI -.000005346
     +    * PMI ** 2 -.00021468 * PMI ** 1.5 -
     +    3.8214 * PMI ** .5 + 10.875 * PMI **
     +    (1./3.) - 1.3975 * LOG (PMI))
      F    =  (3.16E23 * YIELD * PIR2F)/ (4 * 3.1416
     +    * R ** 2)
      PRINT *,'   F = ',F,'   PIR2F = ',PIR2F
C
C     ITERATE TO FIND NEUTRON SURE KILL RANGE
      DO 500 JJ=1,100
          RR=FLOAT(JJ)*.2
         PMI = AIRDEN(M)*RR*10**2
         PIR2F=EXP(-6.775+.005269*PMI-.000005346
     +       *PMI**2-.00021468*PMI**1.5-
     +       3.8214*PMI**.5+10.875*PMI**
     +       (1./3.)-1.3975*LOG(PMI))
         F=3.16E23*YIELD*PIR2F/(4*3.1416*(RR*10**5)**2)
         IF(F.LE.DNSK)THEN
            RNSK = RR
      PRINT *,'   F = ',F,'   PIR2F = ',PIR2F,'   RNSK = ',RNSK
            GO TO 900
         ENDIF
```

```
 508   CONTINUE
908   RNSK=RNSK*10**5
C
C     ITERATE TO FIND NEUTRON SURE SAFE RANGE
      DO 509 KK=1,100
           RR=FLOAT(KK)*.2
         PMI=AIRDEN(M)*RR*10**2
         PIR2F=EXP(-6.775+.005269*PMI-.000005346
     +       *PMI**2-.00021468*PMI**1.5-
     +       3.8214*PMI**.5+10.875*PMI**
     +       (1./3.)-1.3975*LOG(PMI))
         F = 3.16E23*YIELD*PIR2F/(4*3.1416*(RR*10**5)**2)
         IF(F.LE.DNSS)THEN
            RNSS=RR
      PRINT *,'   F = ',F,'   PIR2F = ',PIR2F,'   RNSS = ',RNSS
            GO TO 909
         ENDIF
509      CONTINUE
909   RNSS = RNSS * 10 **5
C
C     CALCULATE PROBABILITY OF NEUTRON KILL
      DNA  =  .5 * LOG (RNSK * RNSS)
      DNB   =  (.5/2.054)*LOG(RNSK/RNSS)
C     CALCULATE WEAPON RADIUS FOR NEUTRONS
      WR   =  EXP(DNA+DNB**2)
      PRINT *,'   DNA = ',DNA,'   DNB = ',DNB,'   WR = ',WR
      PROBA = -.693*(WR/(XX(20)*30.48))**2.
C     CALCULATE SINGLE SHOT PROBABILITY OF RV KILL BY POINT INTERCEPTOR
      IF(ABS(PROBA).GT.23.)THEN
         PROB = 1.
      ELSE
         PROB = 1 - EXP(PROBA)
      ENDIF
      USERF =   PROB
      RETURN
C
```

```
C*********************************************************************
C     USER FUNCTION 8 - PROBABILITY THAT RV DESTROYS TARGET
  8   RN=ATRIB(14)
      IF(ATRIB(2).EQ.1)THEN
         YIELD = XX(21)
C        CALCULATE MISS DISTANCE OF ARV
         SR=SQRT(XX(22)**2*(LOG(1-RN)/(-.693)))
      ELSE
         YIELD = XX(23)
C        CALCULATE MISS DISTANCE OF BRV
         SR=SQRT(XX(24)**2*(LOG(1-RN)/(-.693)))
      ENDIF
      PRINT *,'   RANGE = ',SR
C     SET SURE SAFE OVERPRESSURE FOR TARGET
      DPSS  =  XX(33)
C     SET SURE KILL OVERPRESSURE FOR TARGET
      DPSK  =  XX(34)
      DPA  = .5 * LOG (DPSK * DPSS)
      DPB   =  (.5/2.054) * LOG (DPSK/DPSS)
C     SCALE MISS DISTANCE TO 1 KILOTON EQUIVALENT
      SSR   = SR / YIELD ** (1./3.)
      RR1   = SSR
C     CALCULATE MISS DISTANCE IN M
      STMRM =  RR1 / 3.2815
C     EMPIRICAL FIT FOR OVERPRESSURE CALCULATION
      IF(RR1.EQ.0)THEN
         ANGT(  =  3.1416 / 2
      ELSE
         ANGTT  =  0.
      ENDIF
      P9     =  .01 * EXP(40.3 * STMRM ** (-.295))
      P0     =  .001 * EXP(31.3 * STMRM ** (-.2136))
      DP     =  P9 - (P9-P0) * ((COS(ANGTT))**2)
      PRINT *,'   DP = ',DP
C     ALTERNATE OVERPRESSURE CALCULATION (NOT USED IN MODEL)
      R1=(SR/((1.5*YIELD)**(1./3.)))*.3063048
      DP1=EXP(.19*(LOG(R1))**2-1.5*(LOG(R1))-.1)
      PRINT *,'   DP1 = ',DP1
C     CALCULATE PROBABILITY OF DAMAGE TO TARGET
      Z      =  (LOG(DP)-DPA)/DPB
      IF(Z.LT.0.)THEN
          Z  = ABS ( Z)
          PROB = .5 * ( 1 + .196854 * Z + . 115194 * Z ** 2
     +    + .000344 * Z ** 3 + .019527 * Z ** 4) ** (-4)
      ELSE
          PROB = 1 - .5 * (1 + .196854 * Z + .115194 * Z ** 2
     +    +  .000344 * Z ** 3 + .019527 * Z ** 4) ** (-4)
      ENDIF
C     CALCULATE AVERAGE TARGET DESTRUCTION FOR TARGET AREA
      PROB  =  PROB / XX(26)
```

```
      PRINT *,  'CEP = ',CEP,'  PROB = ',PROB
      USERF  = PROB
C     CALCULATE PROBABILITY OF DAMAGE TO TARGET USING ALTERNATE
C     OVERPRESSURE CALCULATION (NOT USED IN MODEL)
      ZZ     =  (LOG(DP1)-DPA)/DPB
      IF(ZZ.LT.0.)THEN
         ZZ  = ABS ( ZZ)
         PROB = .5 * ( 1 + .196854 * ZZ + . 115194 * ZZ ** 2
     +    + .000344 * ZZ ** 3 + .019527 * ZZ ** 4) ** (-4)
      ELSE
         PROB = 1 - .5 * (1 + .196854 * ZZ + .115194 * ZZ ** 2
     +    +  .000344 * ZZ ** 3 + .019527 * ZZ ** 4) ** (-4)
      ENDIF
      PRINT *,'   PROB = ',PROB
      RETURN
      END
```

Conclusions

The entire code for the model is entered in the computer in the following sequence:

1) JCL cards, first block of code in SLAM support code section

2) *EOR

3) Initial SLAM code, second block of code in SLAM support code section

4) Arriving RV segment of code

5) Endo defense segment of code

6) Point defense swicch segment of code

7) Point defense segment of code

8) Target area segment of code

9) Initializ' cards, last block of code in SLAM support code section

10) SLAM supplementary code as discussed in Chapter IV to carry out the user's experiment

In order to exercise the model from an interactive terminal, the FORTRAN subroutines are then entered, compiled with a file name, and the resulting binary file is stored in a permanent file under the compiled file name. The recommended method of exercising the model is with the interactive terminal, as described. Card decks may also be used. Using this procedure, the FORTRAN subroutines would be entered between steps 2 and 3 of the sequence above, followed by a *EOR card. The user is cautioned to reference the JCL instructions for the particular computer when developing the JCL cards or code.

APPENDIX D

PROGRAM VERIFICATION

Introduction

The purpose of this appendix is to illustrate the verification process that ensured the computer model operated as intended. The example verification compares the output of the supporting subroutines with the results of analytical solutions. These analytical techniques were developed in the three course sequence dealing with the effects of nuclear weapons in the Strategic and Tactical Science program and are based primarily on the information contained in The Effects of Nuclear Weapons by Glasstone and Dolan and A Short Course in Nuclear Weapon Effects by Bridgman and John.

The verification shows a comparison of results of an engagement in the endo-interceptor region using neutron fluence. This is not a test of the random variate generation routines of either the IMSL or the SLAM program. Those are assumed as valid for the purposes of this appendix.

Engagement Verification

The attacker is a maneuvering RV with a yield of 150 kilotons and a CEP of 200 feet. The hardness levels of the RV are shown in Table XV. The defending ABM has a yield of 1 megaton and a CEP of 3000 feet.

The variables, DNA and DNB, can be defined by Eqs (56) and (58).

$$DNA = .5 * \ln(RNSK * RNSS) \qquad (105)$$

$$DNB = \frac{.5}{2.054} * \ln \frac{RNSK}{RNSS} \qquad (106)$$

TABLE XV

MRV Hardness Levels

	X-Rays(cal/cm^2)	Neutrons($neutrons/cm^2$)
Sure Safe	70	1×10^{13}
Sure Kill	100	1×10^{15}

RNSK and RNSS are dependent upon the radiation levels of the engagement. Thus, these must be calculated. The neutron fluence calculation will be used to illustrate the process.

Assuming a miss distance of 853.8 feet and an interception altitude of 22.6744 km (74,391 ft), then the neutron calculation proceeds as follows.

The mass integral, MI, is

$$MI = (\text{air density}) * \text{slant range} * 10^2 \qquad (107)$$

$$\begin{aligned} MI &= (.055006) * (853.8 * .0003048) * 10^2 \\ &= 1.4315\ gm/cm^2 \end{aligned} \qquad (108)$$

The ($4\pi R^2$) fluence is determined using Eq (41).

$$\begin{aligned} PIR2F = e^{(-6.775 + .005269(MI) - .000005346(MI)^2} & \\ {}^{-.00021468(MI)^{1.5} - 3.8214(MI)^{.5}} & \\ {}^{+ 10.875(MI)^{1/3} - 1.3975 \ln(MI))} & \end{aligned} \qquad (109)$$

Since MI = 1.4315, PIR2F = 1.5144, the actual neutron fluence is, then,

$$F = (3.16E23 * 1000 * 1.5144)/(4 * \pi * (853.8 * 30.48)^2)$$

$$= 5.6231 \times 10^{16} \text{ neutrons/cm}^2 \qquad (110)$$

which agrees with the output of the program, 5.6231×10^{16}.

Since the ranges for sure safe and sure kill fluences, RNSS and RNSK, respectively, are dependent of the mass integral, they cannot be calculated directly. An iterative process is used which yields RNSK = 4km and RNSS = 16km. Therefore, using Eqs (56) and (58), DNA = 13.592 and DNB = -.337. Eq (80) is used to calculate the weapon radius (WR).

$$WR = e^{(DNA + (DNB)^2)} = 896,166. \qquad (111)$$

Eq (103) results in the probability of kill.

$$P_k = 1 - e^{\left(-.693 * \left(\frac{896,166}{3000 * 30.48}\right)^2\right)} = \underline{1.0} \qquad (112)$$

APPENDIX E

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Carl L. Critchlow was born on 27 June 1951 in Albuquerque, New Mexico. He graduated from Admiral Farragut Academy in 1969 and attended the United States Military Academy, at West Point, from which he received a Bachelor of Science degree in June 1973. After commissioning as a second lieutenant in the USAF, he spent eighteen months as a civil engineer at March AFB, California before assignment to Minot AFB, North Dakota as a missile combat crew member. While at Minot, he received the degree of Master of Business Administration and served as an evaluator deputy crew commander and crew commander before becoming the 91st Strategic Missile Senior Evaluator and Assistant Chief of the Standardization Division in 1979. He entered the School of Engineering, Air Force Institute of Technology, in August 1980.

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The subject of this thesis is the system consisting of the engagements between attacking intercontinental ballistic missile (ICBM) reentry vehicles (RV) and a defending ballistic missile defense system. The thesis presents a brief overview of the actual system before proceeding with the development of a computer simulation model designed to aid analysis of the system. The primary language of the main program is SLAM; the supporting

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered) programs use FORTRAN V. The RV/Antiballistic missile (ABM) system is modeled as a network through which the RVs flow. The capabilities of the RV with regard to yield and accuracy can be set to the user's desires as can the vulnerabilities of the RV to the two primary kill mechanisms considered, X-ray and neutron radiation. The ABM system consists of a two-tiered, layered terminal defense system with high altitude (70,000 - 150,000 feet) and low altitude (10,000 - 70,000 feet) interceptors. Interceptor yield and accuracy are changeable. Either layer can be activated or deactivated, singly or together, to permit flexibility in the comparison of actual or hypothetical systems. An example simulation is accomplished to demonstrate model operation and permit systemic analysis. The thesis also contains a User's Manual for those interested in using the model.