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System Development Radiation Hardness Assurance

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13. ABSTRACT (*Maximum 200 words*)

The development program for a system with a radiation survivability program is very complex. Careful planning and execution of all phases of the development are necessary from the beginning. When there is a nuclear radiation requirement, Hardness Assurance (HA) must be part of the planning. While this document focuses primarily on activities related to the effects of nuclear radiation on electronic components and materials, a hardness assurance program must include all hostile environments employ balanced hardening concepts at all levels.

It is the intent of this document to point out the agencies and aids available to help in constructing the most effective HA program for a given system and its mission. It is intended to provide guidance to both the system development Project Manager at the sponsoring agency and the Project Manager for the prime contractor.

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SUMMARY

A system development program can be very complex, requiring that many organizations interface and work together successfully. Careful planning and execution are necessary from the beginning. The Hardness Assurance program, that part of the overall development program that assures the radiation survivability of each system produced, requires just such careful consideration from the beginning of the program. For convenience, some of the key items which must be remembered during the development of the HA program are listed below.

- The HA program must be a consideration from the beginning of the system development.
- The HA contractual requirements must be denoted from the beginning, and CDRL DIDs and other guidance are available.
- The HA program depends upon such items as radiation survivability requirements and mission.
- Flow-down of HA responsibilities to the prime contractor and to sub-contractors must be clearly delineated and understood at all levels.
- HA is the part of the overall system development program that addresses radiation survivability and must merge and flow with the management structure of the entire program.
- All activities of the HA program must be documented in some prescribed manner because such documentation is important to other aspects of the life cycle of the system.
- While the HA program may focus on electronic devices, it must cover all aspects of materials and components that could influence survivability.
- The HA plan must include procedures for controlling all changes during the production phase.
- The HA plan, with its procedures, inspections, test techniques, test apparatus, and all aspects of the necessary production controls must be completed prior to the beginning of the production phase.

- The HA plan and program should be sufficiently well defined that it can be properly applied by a second source (a different manufacturing firm) for the production of the system. This is particularly true for large volume tactical systems.
- The HA program should flow into the HM/HS program.

PREFACE

Preparation of this document has been done under the auspices of the DNA Hardness Assurance Committee. Grateful acknowledgement is made to Dr. H. Eisen of ARL, who is the DNA Hardness Assurance Program Area Reviewer, and to L. Cohn (LCDR USN Ret.) the DNA/RAEE project officer, for their helpful guidance and timely reviews. Special thanks is given to R. Nerenberg of BAC for both his written contribution and his commentary, and to W. Alfonte for his helpful discussions and comments. Acknowledgement must also be made of the reviewers who provided comments during the development of this document. These include:

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CONVERSION TABLE

(This Conversion Table is UNCLASSIFIED)

Conversion factors for U.S. Customary to metric (SI) units of measurement.

MULTIPLY →	BY →	TO GET
TO GET ←	BY ←	DIVIDE

angstrom	1.000 000 X E -10	meters (m)
atmosphere (normal)	1.013 25 X E +2	kilo pascal (kPa)
bar	1.000 000 X E +2	kilo pascal (kPa)
barn	1.000 000 X E -28	$meter^2$ (m^2)
British thermal unit (thermochemical)	1.054 350 X E +3	joule (J)
calorie (thermochemical)	4.184 000	joule (J)
cal (thermochemical/cm^2)	4.184 000 X E -2	mega joule/m^2 (MJ/m^2)
curie	3.700 000 X E +1	*giga becquerel (GBq)
degree (angle)	1.745 329 X E -2	radian (rad)
degree Fahrenheit	$t_k = (t°f + 459.67)/1.8$	degree kelvin (K)
electron volt	1.602 19 x E -19	joule (J)
erg	1.000 000 x E -7	joule (J)
erg/second	1.000 000 X E -7	watt (W)
foot	3.048 000 X E -1	meter (m)
foot-pound-force	1.355 818	joule (J)
gallon (U.S. liquid)	3.785 412 X E -3	$meter^3$ (m^3)
inch	2.540 000 X E -2	meter (m)
jerk	1.000 000 X E +9	joule (J)
joule/kilogram (J/kg) radiation dose absorbed	1.000 000	**Gray (Gy)
kilotons	4.183	terajoules
kip (1000 lbf)	4.448 222 X E +3	newton (N)
kip/$inch^2$ (ksi)	6.894 757 X E +3	kilo pascal (kPa)
ktap	1.000 000 X E +2	newton-second/m^2 ($N\text{-}s/m^2$)
micron	1.000 000 X E -6	meter (m)
mil	2.540 000 X E -5	meter (m)
mile (international)	1.609 344 X E +3	meter (m)
ounce	2.834 952 X E -2	kilogram (kg)
pound-force (lbs avoirdupois))	4.448 222	newton (N)
pound-force inch	1.129 848 X E -1	newton-meter (N·m)
pound-force/inch	1.751 268 X E +2	newton/meter (N/m)
pound-force/$foot^2$	4.788 026 X E -2	kilo pascal (kPa)
pound-force/$inch^2$ (psi)	6.894 757	kilo pascal (kPa)
pound-mass (lbm avoirdupois)	4.535 924 X E -1	kilogram (kg)
pound-mass-$foot^2$ (moment of inertia)	4.214 011 X E -2	kilogram-$meter^2$ ($kg \cdot m^2$)
pound-mass/$foot^3$	1.601 846 X E +1	kilogram/$meter^3$ (kg/m^3)
rad (radiation dose absorbed)	1.000 000 X E -2	Gray (Gy)
roentgen	2.579 760 X E -4	coulomb/kilogram (C/kg)
shake	1.000 000 X E -8	second (s)
slug	1.459 390 X E +1	kilogram (kg)
torr (mm Hg, 0° C)	1.333 22 X E -1	kilo pascal (kPa)

*The becquerel (Bq) is the SI unit of radioactivity; 1 Bq = 1 event/s.
**The Gray (Gy) is the SI unit of absorbed radiation.

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SECTION 1

SCOPE

1.1 BACKGROUND.

The U. S. Government is developing a large number of complex systems that are required to function during or after exposure to a radiation environment. The need for these systems to accomplish their designated mission regardless of their complexity and the hostile environments that they must withstand dictates that attention be focused on hardening design techniques and hardness assurance methods used during the development and production phases of the system. While hardness assurance (HA) procedures are implemented during the production phase, there are HA activities that must occur during the earlier design and development phases.

When a system has a survivability requirement, specific radiation criteria are defined and hardening and HA must then be invoked by the developing agency. Hardening is the process of reducing the susceptibility of the system to a nuclear environment to acceptable limits by design and selection of parts and materials. HA consists of those manufacturing controls, lot sample tests, and screens that are applied to assure that the design hardening is not compromised during manufacturing and hence that the radiation response of all of the systems stays within acceptable limits of performance. For example, HA is necessary in parts selection to ascertain that a given part meets the established criteria, and that variations in its radiation response (whether made by one or more manufacturer), do not jeopardize the survivability of the system.

This document is intended to provide guidance to both the system development Project Manager (PM) or System Program Office (SPO) at the sponsoring agency, and the Project Manager for the prime contractor. It will assist the sponsoring agency Project Manager or SPO in establishing survivability requirements and the needed contractual features in the Request for Proposal (RFP), the Statement of Work (SOW), and in identifying Data Item Descriptions (DIDs) for the Contract Data Requirements Lists (CDRLs) for later phases of development. The prime contractor Project Manager will be aided by guidance in the structure and timeline of a Hardness Assurance Program (HAP), the required documentation (such as a Survivability Program Plan), and the HA-related tasks needed as the development of the system progresses through design, development, and production phases.

To be successful, both the hardening and hardness assurance programs must be an integral part of the overall management structure. This existing structure includes design engineers, specification writers, comptrollers, purchasing, QA, value engineers, test engineers, production engineers, reliability engineers, configuration managers and others. Thus, to be most effective each of these groups must include hardness assurance as one of their responsibilities. Each (and all) of these management entities affect the ultimate nuclear survivability of the system just as they affect other aspects of system performance. All must work together as a team and HA activities must not be managed totally separate from the existing management structure. Only when survivability and HA are part of the team will they be viewed as an integral part of the program and accepted by all team members.

Even though this document will allude to various hostile environments as necessary to discuss the concept of balanced hardening, the primary focus will be concerned with nuclear and space radiation effects on electronics and the HA methods and procedures necessary to assure that the system is produced in compliance with hardness design specifications.

1.2 DOCUMENT APPLICATION.

Because this document is intended primarily for program managers and SPOs, it does not discuss the specific details of procedures and methodologies mentioned or referenced that deal with quality control, test techniques or other such items. Instead the document is intended to:

a. Address the planning, hardening, and management approaches required at the system level to ensure that the system is produced in compliance with survivability requirements.

b. Provide guidance in defining HA activities commensurate with the threat nuclear weapon and space radiation environment and with the concept of balanced hardening to all hostile environments. These guidelines are aimed primarily at system development agencies, project managers and their contractors.

1.3 RELATIONSHIP TO MIL-HDBK-814, MIL-HDBK-815, and MIL-HDBK-816.

A major task in developing a system that has a nuclear or space radiation survivability requirement is the selection and qualification of electronic pieceparts to the hardness specifications. Because parts play a fundamental role in the survivability of the system, they will be mentioned frequently. However, the procedures that may be employed in the selection and qualification process will not be discussed in this document. MIL-HDBK-814, "Ionizing Radiation and Neutron Hardness Assurance;" MIL-HDBK-815, "Dose Rate Hardness Assurance;" and MIL-HDBK-816, "Guidelines For Developing Specifications for Radiation Hardness Assured Devices;" discuss in detail the HA aspects of parts selection and qualification. These details are of paramount importance because system survivability is achieved and maintained through proper specifications, the selection of adequately hard parts, quality assurance, and configuration control. However, the selection and structure of the HA activities necessary to achieve the objectives sought in this process remain a management decision.

1.4 DOCUMENT OBJECTIVES.

The major objectives of this Handbook are to:

a. Provide guidelines to structure a HA program addressing all phases of system development and production to ensure that the system complies with radiation hardness and survivability specifications. This HA program structure will include techniques employed at the system level as well as the HA data and procedures needed at the piecepart and other lower-tier levels. It will present the relationship of design hardening and verification to HA and Hardness Maintenance/Hardness Surveillance (HM/HS).

b. Present a description of HA activities and HA program deliverables for all phases of the program. This description will include the responsibility of subcontractors that are part of the development effort and will include tasks such as defining qualification tests, special hardware and software, and necessary documentation.

c. Show a timeline for the HA program, its major activities and its outputs.

d. Give references for existing documents that will assist in devising the HA procedures and test techniques, and in piecepart HA testing and control methods.

SECTION 2

APPLICABLE DOCUMENTS

2.1 DOCUMENTS FOR HARDNESS ASSURANCE PROGRAMS.

Many of the following documents will be useful in implementing an HA program. Most were generated by the HA community.

2.1.1 Military Handbooks.

1. MIL HANDBOOK 814: IONIZING RADIATION AND NEUTRON HARDNESS ASSURANCE.

2. MIL HANDBOOK 815: DOSE RATE HARDNESS ASSURANCE; (Early version also available as DNA-TR-86-29, November 1988.).

3. MIL HANDBOOK 816: GUIDELINES FOR DEVELOPING SPECIFICATIONS FOR RADIATION HARDNESS ASSURED DEVICES; (Early version also available as DASIAC-90-115, March 1990.).

4. MIL HANDBOOK 339 APPENDIX; CUSTOM LARGE SCALE INTEGRATED CIRCUIT DEVELOPMENT AND ACQUISITION FOR SPACE VEHICLES; January 1986.

2.1.2 DoD Directives and Instructions.

1. DoD Directive 5000.1, DEFENSE ACQUISITION, February 1991.

2. DoD Instruction 5000.2, DEFENSE ACQUISITION MANAGEMENT POLICIES AND PROCEDURES, especially Part 6, Section F, SURVIVABILITY, February 1991.
3. DoD Manual 5000.2-M, DEFENSE ACQUISITION MANAGEMENT DOCUMENTS AND REPORTS, February 1991.

2.1.3 Data Item Descriptions.

1. "Nuclear Hardness and Survivability Program Plan," DI-ENVR-80262.
2. "Hardness Assurance Plan," DI-ENVR-80263.
3. "Hardness Maintenance Plan," DI-ENVR-80264.
4. "Hardness Surveillance Plan," DI-ENVR-80265.
5. "Nuclear Hardness and Survivability Design Analysis Report," DI-ENVR-80266.
6. "Nuclear Hardness and Survivability Trade Study Report," DI-ENVR-80267.
7. "Transient Radiation Effects on Electronics (TREE) Hardening Plan," DI-ENVR-80387.
8. "Hardness Data Manual Maintenance Document," DI-M-30412A.
9. "Nuclear Survivability Program Plan," DI-NUOR-80156A.
10. "Nuclear Survivability Test Plan," DI-NUOR-80928.
11. "Nuclear Survivability Test Report," DI-NUOR-80927.
12. " Nuclear Survivability Design Parameters," DI-NUOR-80927.
13. "Nuclear Survivability Assurance Plan," DI-NUOR-80926.
14. " Nuclear Survivability Maintenance/Surveillance Plan," DI-NUOR-81025.

2.2 MILITARY STANDARD TEST METHODS.

1. Method 1015, STEADY STATE PRIMARY PHOTOCURRENT, MIL-STD 750.
2. Method 1017, NEUTRON IRRADIATION, MIL-STD-750 AND MIL-STD-883.
3. Method 1019, STEADY STATE TOTAL DOSE IRRADIATION PROCEDURE, MIL-STD 750 AND MIL-STD-883.

4. Method 1020, RADIATION-INDUCED LATCHUP TEST PROCEDURE, MIL-STD-883.

5. Method 1021, DOSE RATE THRESHOLD FOR UPSET OF DIGITAL MICROCIRCUITS, MIL-STD-883.

6. Method 1022, MOSFET THRESHOLD VOLTAGE, MIL-STD-883.

7. Method 1023, DOSE RATE RESPONSE OF LINEAR MICROCIRCUITS, MIL-STD-883.

8. Method 3404, MOSFET THRESHOLD VOLTAGE, MIL-STD-750.

9. Method 3478, POWER MOSFET DOSE RATE EFFECTS, MIL-STD-750.

2.3 ASTM DOSIMETRY STANDARDS.

1. E263, Method for DETERMINING FAST-NEUTRON FLUX BY RADIOACTIVATION OF IRON.

2. E264, Method for DETERMINING FAST-NEUTRON FLUX BY RADIOACTIVATION OF NICKEL.

3. E265, Method for DETERMINING FAST-NEUTRON FLUX BY RADIOACTIVATION OF SULFUR.

4. F526, Method of DOSE MEASUREMENT FOR USE IN LINEAR ACCELERATOR PULSED RADIATION EFFECTS TESTS.

5. E665, Method for DETERMINING ABSORBED DOSE VERSUS DEPTH IN MATERIALS EXPOSED TO THE X-RAY OUTPUT OF FLASH X-RAY MACHINES.

6. E666, Method for CALCULATION OF ABSORBED DOSE FROM GAMMA OR X RADIATION.

7. E668, Practice for the Application of THERMOLUMINESCENCE-DOSIMETRY (TLD) SYSTEMS FOR DETERMINING ABSORBED DOSE IN RADIATION-HARDNESS TESTING OF ELECTRONIC DEVICES.

8. E720, Guide for SELECTION OF A SET OF NEUTRON-ACTIVATION FOILS FOR DETERMINING NEUTRON SPECTRA USED IN RADIATION-HARDNESS TESTING OF ELECTRONICS.

9. E721, Method for DETERMINING NEUTRON ENERGY SPECTRA WITH NEUTRON-ACTIVATION FOILS FOR RADIATION-HARDNESS TESTING OF ELECTRONICS.

10. E722, Practice for CHARACTERIZING NEUTRON ENERGY FLUENCE SPECTRA IN TERMS OF AN EQUIVALENT MONOENERGETIC NEUTRON FLUENCE FOR RADIATION HARDNESS TESTING OF ELECTRONICS.

11. E763, Method for CALCULATION OF ABSORBED DOSE FROM NEUTRON IRRADIATION BY APPLICATION OF THRESHOLD-FOIL MEASUREMENT DATA.

12. E820, Practice for DETERMINING ABSOLUTE ABSORBED DOSE RATES FOR ELECTRON BEAMS.

13. E845, Methods for CALIBRATION OF DOSIMETERS AGAINST AN ADIABATIC CALORIMETER FOR USE IN FLASH X-RAY FIELDS.

14. E1026, Method for USING THE FRICKE DOSIMETER TO MEASURE ABSORBED DOSE IN WATER.

15. E1027, Practice for EXPOSURE OF POLYMERIC MATERIALS TO IONIZING RADIATION.

16. E1205, Method for USING THE CERIC-CEROUS SULFATE DOSIMETER TO MEASURE ABSORBED DOSE IN WATER.

17. E1249, Practice for MINIMIZING DOSIMETRY ERRORS IN RADIATION HARDNESS TESTING OF SILICON ELECTRONIC DEVICES.

18. E1250, Method for APPLICATION OF IONIZATION CHAMBERS TO ASSESS THE LOW ENERGY GAMMA COMPONENT OF CO-60 IRRADIATORS IN THE RADIATION HARDNESS TESTING OF SILICON ELECTRONIC DEVICES.

2.4 ASTM ELECTRICAL MEASUREMENT AND RADIATION TEST STANDARDS.

1. F448, Method for MEASURING STEADY-STATE PRIMARY PHOTOCURRENT.

2. F528, Method of Measurement of COMMON-EMITTER D-C CURRENT GAIN OF JUNCTION TRANSISTORS.

3. F570, Method for TRANSISTOR COLLECTOR-EMITTER SATURATION VOLTAGE.

4. F615, Practice for DETERMINING SAFE CURRENT PULSE OPERATING REGIONS FOR METALLIZATION ON SEMICONDUCTOR COMPONENTS.

5. F616, Method for MEASURING MOSFET DRAIN LEAKAGE CURRENT.

6. F617, Method for MEASURING MOSFET LINEAR THRESHOLD VOLTAGE.

7. F618, Method for MEASURING MOSFET SATURATED THRESHOLD VOLTAGE.

8. F632, Method for MEASURING SMALL-SIGNAL COMMON EMITTER CURRENT GAIN OF TRANSISTORS AT HIGH FREQUENCIES.

9. F675, Method for MEASURING NONEQUILIBRIUM TRANSIENT PHOTOCURRENTS IN p-n JUNCTIONS.

10. F676, Method for MEASURING UNSATURATED TTL SINK CURRENT.

11. F744, Method for MEASUREMENT OF DOSE RATE THRESHOLD FOR UPSET OF DIGITAL INTEGRATED CIRCUITS.

12. F769, Method for MEASUREMENT OF TRANSISTOR AND DIODE LEAKAGE CURRENTS.

13. F773, Method for MEASURING DOSE RATE RESPONSE OF LINEAR INTEGRATED CIRCUITS.

14. F774, Guide for ANALYSIS OF LATCHUP SUSCEPTIBILITY IN BIPOLAR INTEGRATED CIRCUITS.

15. F867, Guide for TOTAL DOSE RADIATION TESTING OF SEMICONDUCTOR DEVICES.

16. F980, Guide for THE MEASUREMENT OF RAPID ANNEALING OF NEUTRON-INDUCED DISPLACEMENT-DAMAGE IN SEMICONDUCTOR DEVICES.

17. F996, Method for DETERMINING THE MEAN INTERFACE TRAP DENSITY OF MOSFETs BY CHARGE PUMPING.

18. F1032, Guide for MEASURING TIME-DEPENDENT TOTAL-DOSE EFFECTS IN SEMICONDUCTOR DEVICES EXPOSED TO PULSED IONIZING RADIATION.

19. F1096, Guide for MOSFET SATURATION THRESHOLD VOLTAGE.

20. F1190, Practice for NEUTRON IRRADIATION OF UNBIASED ELECTRONIC COMPONENTS.

21. F1191, Guide for THE RADIATION TESTING OF SEMICONDUCTOR MEMORIES.

22. F1192, Guide for THE MEASUREMENT OF SINGLE EVENT PHENOMENA FROM HEAVY ION IRRADIATION OF SEMICONDUCTOR DEVICES.

23. F1467, Guide for THE USE OF AN X-RAY TESTER ($\approx$ 10 keV PHOTONS) IN AN IONIZING RADIATION EFFECTS TESTING OF MICROELECTRONIC DEVICES.

2.5 APPLICABLE REFERENCES.

1. MIL-HDBK-279, "Total Dose Hardness Assurance Guidelines for Semiconductor Devices and Microcircuits," 25 January 1985.

2. MIL-HDBK-280, "Neutron Hardness Assurance Guidelines for Semiconductor Devices and Microcircuits," 19 February 1985.

3. Price, W., Martin, K., and Gauthier, M., "Total Dose Hardness Assurance Guidelines for Semiconductor Devices," DNA-5909F, 1 February 1982.

4. Namenson, A., et al., "Piecepart Neutron Hardness Assurance Guidelines for Semiconductor Devices," DNA-5910F, 6 October 1981.

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11. DoD-STD-100, "Engineering Drawing Practices," December 1978.

12. MIL-HDBK-780, "Standardized Military Drawings," August 1987.

13. MIL-STD-1546B "Parts, Materials, and Processes Standardization, Control, and Management Program For Spacecraft and Launch Vehicles."

14. MIL-STD-1547B(USAF), "Electronic Parts, Materials and Processes for Space and Launch Vehicles, Technical Requirements for," December 1987.

15. MIL-STD-339(USAF), "Custom Large Scale Integrated Circuit Development and Acquisition for Space Vehicles," 31 July 1984.

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18. Rose, M., et al., "Design Guidelines for Transient Radiation Effects on Tactical Army Systems," HDL-CR-81-015-1, (NTIC # AD-B-060-708L), July 1981.

19. Halpin, J., et al., "Nuclear Weapon Effects on Army Tactical Systems," HDL-TR-1882-1, Vol. 1, Army Research Laboratory, Adelphi, MD, April 1979.

20. MIL-STD-414, "Sampling Procedures and Tables for Inspection by Variables for Percent Defective," 11 June 1957.

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23. Natrella, M.D., "Experimental Statistics," Handbook 91, U.S. Dept. of Commerce, Nat. Bureau of Standards, August 1963.

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26. Namenson, A., "Hardness Assurance and Overtesting," IEEE Trans. Nucl. Sci., NS-29, 1821, No. 6, December 1982.

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31. Heidrich, R., "The Management of Nuclear Hardened Parts," AQI Project 77-14, Air Force Logistics command, Directorate of Logistics Integration, Wright-Patterson Air Force Base, Ohio, October 1977.

32. AFR 80-38, "The Air Force System Survivability Program," September 1989.

33. AR 70-60, "Nuclear Survivability of Army Materiel," October 1984.

34. O'Hara, J., et al, "Program Management Handbook on Nuclear Survivability," DNA-H-90-30, November 1990.

35. Alexander, D.R., "Radiation Effects Test Chip Guidelines," HDL-CR-91-043-1, November 1991.

36. DoD-STD-1766A, "NH&S Program Requirements for ICBM Weapon Systems," 01 December 1986.

37. MIL-STD-1809, "Space Environment for USAF Space Vehicles," 15 February 1991.

2.6 IMPORTANT DOCUMENTS: SPECIAL ATTENTION.

Special attention is called to the new DoD Directive 5000.1, "Defense Acquisition;" the DoD Instruction 5000.2, "Defense Acquisition Management Policies and Procedures;" and the DoD Manual 5000.2-M, "Defense Acquisition Management Documents and Reports." All are a recent release (February 1991) and replace the 1987 versions of the same documents as well as about 60 previous directives. Of particular interest to HA is the inclusion of DoDD 4245.4, "Acquisition of Nuclear Survivable Systems," into the revised version of DoDI 5000.2. Note that Part 6, Section F, of DoDI 5000.2 is entitled "Survivability," and includes such topics as Hardened Systems (HA and HM/HS), Test and Evaluation, and Life-Cycle Survivability.

2.7 DEVICE DATA BASES.

There are a number of device data bases already in existence. When utilizing data from such sources, care should always be exercised regarding the manner in which the data were taken, the age of the data, and its applicability to the system being developed.

SECTION 3

DEFINITIONS

KEY DEFINITIONS.

To aid the reader in understanding the intention of this document, some pertinent terms and definitions are presented below and within appendices "A" and "B".

Hardness Assurance (HA) - The application of manufacturing controls, lot sample tests, test procedures, and screens used to assure that the designed hardness of the system is retained during system production. Although the primary application of HA is in the production phase, HA activities during the Engineering and Manufacturing Development (EMD) phase are necessary.

Hardness Verification (HV) - The determination through a sequence of tests and analyses that a system design is in fact hardened in compliance with the hardness requirements.

Hardness Maintenance (HM) - The procedures applied during the operational phase of a hardened system to make sure that the hardness built into the system is retained throughout the life of the system.

Hardness Surveillance (HS) - Those inspection and test procedures that are conducted during the operational life of the system to ensure that the designed hardness of the system is not degraded through operational use, logistic support or maintenance actions.

Hardness Assurance, Maintenance and Surveillance (HAMS) - This terminology will not be used in this document because of the ambiguity associated with the acronym. HAMS also stands for Hardness Assurance Monitoring System.

SECTION 4

GENERAL REQUIREMENTS

4.1 THE HARDNESS ASSURANCE PROGRAM.

Hardness Assurance (HA) is a program that becomes operative primarily during system production. However, as noted, the HA program is not suddenly developed when the Production Phase begins. Before a HA program can be implemented for production, HA activities and planning must occur during CD, D/V, and EMD. They provide the basis for the HA activities during production. Regardless of the differences that may exist in system requirements and mission, there are some common elements that should be a part of hardness assurance programs. Despite the uniqueness of the program, these common features are:

a. Survivability decisions must be based on radiation response data.

b. Pieceparts must be sorted into hardness critical categories and the hardness critical items must be identified.

c. Piecepart acceptance procedures must be developed and implemented.

d. Radiation hardness must be validated by testing and analysis to the maximum extent practicable, and

e. Controls must be in place to prevent deleterious changes from being made.

f. Test, analysis, and design activities must be completed to verify the system nuclear hardness and survivability.

4.2 FEATURES OF HA PROGRAMS.

4.2.1 Development Phases.

The need to guarantee hardness drives the requirement to consider HA during all program phases. There should be a logical progression from a properly designed hardened system, to hardness features properly implemented (HA), to hardness verification (HV), to hardness features to be maintained and inspected (HM/HS). The hardness control mechanisms needed to ensure that the design is translated into survivable production units can be put in place the day production begins only if there has been adequate prior preparation.

4.2.1.1 **The CD Phase**. During CD, the hardness criteria and environmental specifications must be developed so that the hardened design of the overall system can begin. All system requirements should accurately reflect the mission of the system. Possible system designs should now be evaluated for their impact on life cycle survivability issues including the cost of HA.

4.2.1.2 **The D/V Phase**. During the D/V phase, the system concept becomes firmer and it is possible to assess the hardness of the system. At this point it is important to consider the types of HA approaches that fit into the D/V hardware concepts. Some examples are: (1) design margin; (2) hardness dedicated features; (3) test, inspection, or verification methods; and (4) the HA controls to be used. These questions and other similar concerns for achieving the required survivability must be addressed in the EMD stage.

4.2.1.3 **The EMD Phase**. The EMD phase typically requires HA planning as a formal requirement with a HA plan as a contract deliverable. To make sure that the HA plan is meaningful, it must reflect both a design verified to be hard and realistic activities that will assure that hardness is transferred from drawing to production unit. Hardness verification is required during EMD to qualify the design hardware to the requirements, usually by piecepart, sub-system or system radiation effects testing. This is typically documented at a major program milestone such as a Design Review or a Configuration Audit. Although hardness verification may be considered as an activity separate from HA, it is an integral part of the HA Plan. If the HA Plan relies on piecepart design margin to assure a lower bound on the system hardness, this design margin must be demonstrated. Whatever hardness levels are found by hardness verification must be maintained throughout the life cycle. If hardness verification testing reveals little margin above the criteria requirements, the HA plan must include controls sufficiently sensitive and rigorous to identify relatively small changes in radiation response performance. Hardness assurance testing and inspection must be structured to positively verify that pieceparts with small design margins cannot cause system failure at the criteria level. On the other hand, hardness verification may reveal that large design margins exist, whether through purposeful design or through intrinsic hardness. If so, less costly HA approaches mechanisms such as material source controls, existing quality inspections and configuration management should be reviewed to see if they are sufficient.

4.2.1.4 **Production Activities**. The HA plan should also reflect an overall program management approach. As the contractor looks ahead to production, certain management tools will be used to execute and monitor results of the HA activities during production. These include:

a. Documentation of inspections

b. Definition of interactions between engineering and manufacturing that will control the system configuration.

c. Maintaining engineering data needed to insure hardness throughout the life cycle of the system.

d. Annotation of the drawings for Hardness Critical Items (HCIs).

e. Implementation of a Hardness Critical Process (HCP).

f. Implementation of field maintenance instructions to insure that hardness is maintained in deployed systems.

Clearly the HA plan must be an evolving document during EMD. It must start by proposing an effective plan based on the best hardness estimates from D/V. The plan must be modified to reflect design changes that occur during EMD. At the end of EMD, with the design stabilized, the HA plan should provide cost effective controls as well as mechanisms to execute these controls. With these tasks accomplished, the Production phase begins and the HA Plan is executed.

4.2.2 Key Elements of HA.

HA evolved as a discipline to ensure that hardened designs are translated into actual hardened systems. Thus, the primary features of HA programs are those that in some way assure the manufacture of a hardened system from a hardened design. It might be expected that simple adherence to drawings would be sufficient to maintain hardness. In practice, it has been found that a number of mechanisms must operate to guarantee that hardness is maintained. These mechanisms are usually expressed as controls and are discussed in the following sections. The hardness of the components used in the equipment is determined by using:

a. environmental response tests

b. measurements

c. inspections and demonstrations to show compliance with specifications

The use of hardened components in the system is controlled by:

a. production constraints imposed by QA/QC.

b. parts and materials controls

c. configuration management

In addition, the probability of survivability of systems is often increased through the use of design margins. While not strictly a control, piece part design margins can help ensure a lower bound on hardness. The implementation of design margins is described in detail in MIL-HDBKs 814 and 815 (See Section 5.9.3).

4.2.3 HA Activities Overview.

Since HA programs are implemented to assure the hardness quality of production material, the key elements of a HA plan are both procedures that control the hardness of the end item by controlling the design materials, and processes that yield a hardened product. In cases where the hardness of a component is easily verified through physical or electrical response to the environment of interest, simulated environmental testing is a cost-effective method for HA. If the testing is not destructive and not too costly, 100% component testing may be used to assure hardness. An example is latchup screening testing. When testing is destructive or costly, statistical sampling is often used. For example, a certain percentage of components may be randomly chosen from a production lot for destructive radiation testing. If the sample passes, statistical theory allows an inference of a certain probability that the entire lot would pass if tested. The number of samples can be adjusted to allow inference of a suitably high probability of rejection of a defective lot.

4.2.3.1 **Key Measurements**. Measurements of pre-test characteristics may be adequate for hardness assurance of some items. Pre-exposure determination of a bipolar transistor gain-bandwidth product, f_T, is an example for estimating hardness to neutron radiation. Such a procedure may be useful in weeding out components that would suffer too much degradation to be acceptable. Another example is the measurement of transfer impedance of shielding as used for EMP HA to verify that the assumed amount of field attenuation is present. In some instances, verification of the presence of components may be enough to assure some hardness level. Inspection of shielding, proper cable terminations and correct grounding practices are good examples for EMP. Inspection of the proper placement of current limiting resistors or diodes is applicable for hardness dedicated components. In these cases, simple inspections may be enough to ensure hardness. In situations where the equipment uses more complicated methods for mitigating nuclear weapons effects, test demonstrations may be required. An example of such a situation occurs when a processor is designed to circumvent and reset following a radiation pulse. If the circumvention hardware is designed to include a self-test capability, the reset function could be demonstrated any time from initial production to acceptance testing to maintenance surveillance testing. Such demonstrations would be a necessary part of a HA program.

4.2.3.2 **Configuration Management**. The prime contractor is usually required to develop a configuration management program. Configuration management, often accomplished by means of a Configuration Control Board, requires the cooperative efforts of many functions including value engineering, production engineering, survivability engineering, QC, reliability, QA, and component engineering. The hardness assurance program documentation must state that all potential changes to the hardened design must be submitted to the CCB for analysis and approval. (See Section 5.9.1.1 and Figure 5.6.) A key item for HA is the requirement of DOD-STD-100 for marking of Hardness Critical Items (HCIs) and Hardness Critical Processes (HCPs) on drawings. (See Glossary for definitions.) The standard requires drawings to contain both HCI/HCP markings and a note which states, "All changes to or proposed substitutions of HCIs or HCPs must be evaluated for hardness impacts by the Configuration Control Board and the engineering activity responsible for survivability." Adherence to HCI/HCP marking requirements is essential for controlling changes to the hardened design. The hardening program must include some method of insuring proper annotation of drawings. HA is helped through related requirements in the existing configuration control process. According to MIL-STD-973, configuration control is the "systematic proposal, justification, evaluation, coordination, approval, or disapproval of proposed changes, and the implementation of all approved changes in the configuration of a Configuration Item after formal establishment of its baseline." Configuration controls serve the interest of HA if they can identify any deviations from the baseline hardened design. Once identified, the control system should allow the change only if hardness is not degraded. This requires a HA program with a close, effective working relationship between the contractor configuration control organization and the survivability organization.

4.2.3.3 Parts and Materials Control. Closely allied to configuration controls are parts and materials controls. These include controls imposed on component suppliers such as the use of captive semiconductor lines, and Specification Drawings (e.g., SMD and SCD) with specific radiation requirements and contractual change notification requirements. A wide range of vendor controls is available. They may be expensive, however, if they force vendors to deviate significantly from typical commercial procedures. The contractor's normal material procurement activities must be responsive to hardening requirements and must consider all proposed changes and identify any changes that could cause a change in hardness of the items acquired for production. In a similar manner, production and manufacturing controls must also ensure proper use and assembly of hardness critical components. Quality Assurance/Quality Control activities are often the primary agent for ensuring that HCIs and HCPs are properly applied. In some cases, contractors may be required to classify, mark and track critical characteristics including hardness. Even if this type of requirement is not imposed, many contracts require adherence to the quality requirements of MIL-I-45208 and MIL-Q-9858. These general quality specifications can have considerable impact on assuring hardness if Quality Assurance personnel understand the significance of their actions on the ultimate hardness of the system.

4.2.3.4 Helpful MIL-STDs. MIL-I-45208 requires that the QA inspection system provides for procedures which will ensure that the latest applicable drawings, specifications and instructions required by the contract are used for fabrication, inspection and testing. This can be instrumental in ensuring that proper components and methods are used and that any HA related testing or inspection is performed correctly. MIL-Q-9858 requires that materials and products be subjected to inspection upon receipt to the extent necessary to ensure conformance to technical requirements. This presents an obvious mechanism for HA inspections discussed above. The QA department uses drawings and specifications developed during the EMD program as guidelines for these inspections. If the verification process has established that adherence to such drawings and specifications results in a hardened configuration for the equipment, normal QA manufacturing controls will provide assurance that materials used during processing possess the necessary hardness attributes. In a similar manner, MIL-Q-9858 requires that processing and fabrication are accomplished under controlled conditions, including documented work instructions. Such instructions rely on the drawings developed during EMD. QA activities which enforce processing based on drawings that are properly marked for HCIs and HCPs can therefore ensure that the hardened design is maintained throughout fabrication. To fully utilize the HA benefits of these actions, the contractor should include a HA awareness training program as part of a comprehensive HA program. The training should be required for key Material, Production and Quality personnel. Once these personnel understand the intent and needs of HA concepts, they can institute an array of hardness control mechanisms at very low additional cost. Also note that the same data and details covered in the HA awareness training can be utilized in the HM/HS Plans.

4.2.3.5 Design Margin Concept. The design strategy of providing reasonable design margins can be used as an HA strategy. Design margin strategies include using additional shielding, insertion of additional protective components such as resistors, limiters or filters, circumvention, and most typically, the use of harder components and circuit design rules that utilize derated component parameters. In cases where the radiation requirements are not too severe, judicious choice of parts (or vendors) to be used in the design process can often provide extra margin at little cost. This is an approach often favored by system managers since it may allow the program to avoid all other HA activities if the margins are high enough. The decision to utilize these methods must of course be exercised during EMD. Design margin is unique among HA approaches in that it must be both planned and executed before production begins. (See MIL-HDBKs 814 and 815.)

SECTION 5
DETAILED REQUIREMENTS

5.1 HA PROGRAM DEFINITION.

As discussed in earlier sections, the final implementation of the HA program will depend upon the system and its mission. The uniqueness of each system is just another reason why each HA program must be an integral part of the overall system development. In the following sections, a more detailed illustration of an HA program is presented.

5.1.1 Importance of Early Inclusion of HA Program.

Ideally, the first consideration of the HA plan for the production of a system should be in the RFP so that the HA program can be developed with the system. It should be evident that the HA program is unique to each system just as every system is unique with different requirements and missions. It will be seen that many HA procedures are utilized during the design and development phases of a system. For instance, in the selection of electronic devices capable of meeting the hardness requirements, many of the established HA procedures can be used.

5.2 SYSTEM DEVELOPMENT BACKGROUND: HOSTILE THREATS.

In developing a system for space, tactical or strategic use, there are a large number of environments to consider, many of which are hostile to system survivability. The effects of these hostile environments must be mitigated so that the system can perform its mission. These environments can be both nuclear and non-nuclear in nature. The nuclear environments include the direct or primary radiation as well as the secondary environments and phenomena. The primary environments from a nuclear detonation are the neutrons, gammas, x-rays and fission products. Depending upon the scenario, these in turn produce the EMPs* (HEMP, MHDEMP,

*See the Glossary for commonly used acronyms such as these.

SREMP, IEMP, and ECEMP), blast, shock, thermomechanical shock (TMS), and thermal radiation. If the mission of the system is in space, the natural radiations - electrons, protons, solar flare radiation, and cosmic rays - must be considered. For some space systems, both the nuclear and the natural space environments must be considered. For some missions, other natural phenomena such as lightning can be quite hostile. Other non-nuclear environments that may need to be considered include laser, neutral particle beam (NPB), high powered microwave (HPM), electromagnetic interference (EMI) and several forms of kinetic energy (KE).

5.2.1 Nuclear and Space Radiation.

Because it is the intent of this document to discuss the HA activities associated with mitigating the effects of the nuclear and space radiation, these environments will be discussed in more detail. Hardening of a system to nuclear and space radiation usually occurs through shielding applied to specific circuits and sub-systems, design techniques, and the use of hardened parts. The primary radiations from a nuclear detonation manifest themselves in widely differing manners, depending upon where the detonation occurs. The products of a nuclear detonation are x-rays, gamma rays, neutrons and fission products. For an exo-atmospheric detonation, the x-rays are the dominant output. Fortunately, x-rays can be effectively shielded and design guidelines exist which allow the x-rays to be shielded to an appropriate level which can be as low as the level of the gamma-rays (which cannot be effectively shielded). To use an example appropriate to a space craft, x-rays (with a 6 to 10 keV bb spectrum) will be attenuated by more than a factor of 10 when passing through 60 mils of aluminum,** while a 1 MeV gamma ray will be attenuated about 1 percent. Neutrons are also effectively impossible to shield. The primary radiations from a nuclear detonation in order of concern for hardening a system in space are x-rays, gamma rays, neutrons, and enhanced electrons for satellites in some orbits.

**DNA Effects Manual, No. 1, DNA EM-1, Chap. 22 "Damage to Space Systems" Nov 1990, (SRD). (See Section 22V)

5.2.1.1 **Atmospheric Case**. If the nuclear detonation is endo-atmospheric, the environments are changed somewhat. The x-rays are converted to thermal radiation, shock and blast, but the gammas (including fallout) and neutrons remain because of their extreme penetrating capability. The dominant environment now depends upon parameters such as altitude and mission of the system (manned or unmanned). The secondary threats also change: SGEMP is still present, but with different characteristics because it is being generated by photons with different spectral characteristics. Also an electromagnetic threat designated as SREMP occurs for systems near the detonation.

5.2.1.2 **Space Case**. For systems in space, the natural space environment, must be considered in addition to the radiation from nuclear detonations. The natural radiations of interest are trapped electrons, protons, and cosmic rays. The electrons and protons exist in a relatively wide range of energies. The dose from the electrons is dependent upon the orbit of the spacecraft because the highest concentrations of the electrons exist in the Van Allen belts (including the electrons from a nuclear detonation that are trapped there), and the exposure will depend upon the time the spacecraft spends in these belts. In some cases, the electrons can produce an undesirable spacecraft charging.

5.2.1.3 **Single Event Effects**. Cosmic rays are usually very high energy ions that cause single event effects (SEE) such as upset, latchup and burnout. Shielding is not effective in eliminating SEE, so other methods such as device hardening against SEE and/or error detection and correction (EDAC) must be utilized as needed for the mission of the system. For some space-based systems, SEE is the foremost hardening consideration. In such cases, parts hardened to SEE should be selected during D/V or EMD to avoid the costly "fix" necessary of the problem when detected later in the program.

5.2.2 Balanced Hardening Concept.

A complete survivability program will generally include other system threats in addition to nuclear or space radiation. Depending upon the mission of the system and other circumstances, these other threat environments may be more stressing to the system than radiation. The amount of attention given to a particular threat environment should be both proportional to its relative importance and also treated cooperatively with hardening activities for other environments. This necessitates a balanced approach to hardening. There is, for example, little use in providing extreme hardening measures for nuclear radiation while ignoring hardening against EMP. A complete discussion of hardness verification and hardness assurance activities for these other threats is beyond the scope of this document, but they may be found in other reports and guidelines. (Refs. 5, 6, 18, 19, 20). For example, in addition to the noted references, there are guideline documents dealing with hardening techniques for other hostile environments. Several such documents for EMP are:

1. MIL-HDBK-423, "High-Altitude Electromagnetic Pulse (HEMP) Protection For Fixed and Transportable Ground-Based C^4I Facilities," Vol. 1, June 1992.
2. Phillips Laboratory, "Nuclear Electromagnetic Pulse Hardness Verification Methods for Aerospace Systems," June 1992.
3. AFWL-TR-73-68, "Electromagnetic Pulse Handbook For Missiles And Aircraft In Flight," September 1972.

The important point is that the sponsoring agency and contractor ensure that a comprehensive systems engineering analysis be performed to identify all survivability requirements and assign a proper level of hardening effort to each one.

5.2.3 Emphasis on Electronics.

Although there are many design aspects to consider when deriving the design specification for a hardened system, it quickly becomes evident that electronic devices are the focus of attention. Historically, it has been recognized that these active devices are usually the items most sensitive to the hostile radiation environments. Accordingly, they receive attention because the electronic payloads are necessary for the system to operate and perform its mission. The emphasis on electronic devices will also be the case in this document since many of the HA activities will be related to the selection and qualification of these devices.

5.3 LIFE CYCLE SURVIVABILITY AND HARDNESS APPROACH.

Survivability requirements do not cease with the completion of system design and verification. Survivability must be actively considered throughout the entire life cycle to ensure that the operational system retains the desired attributes.

5.3.1 Hardness Activity Flow.

DoD programs are considered to have life cycles composed of distinct phases. This concept is useful for any system, since it clearly defines milestones that must be met to ensure proper review of design feasibility. Just as programs have defined phases encompassing particular tasks, the survivability life cycle may be viewed as a continuum of activities. Since these activities are a function of the overall program phase in which they occur, it is instructive to view them in context of the major program phases and in relationship to one another. Figure 5-1 shows these relationships.

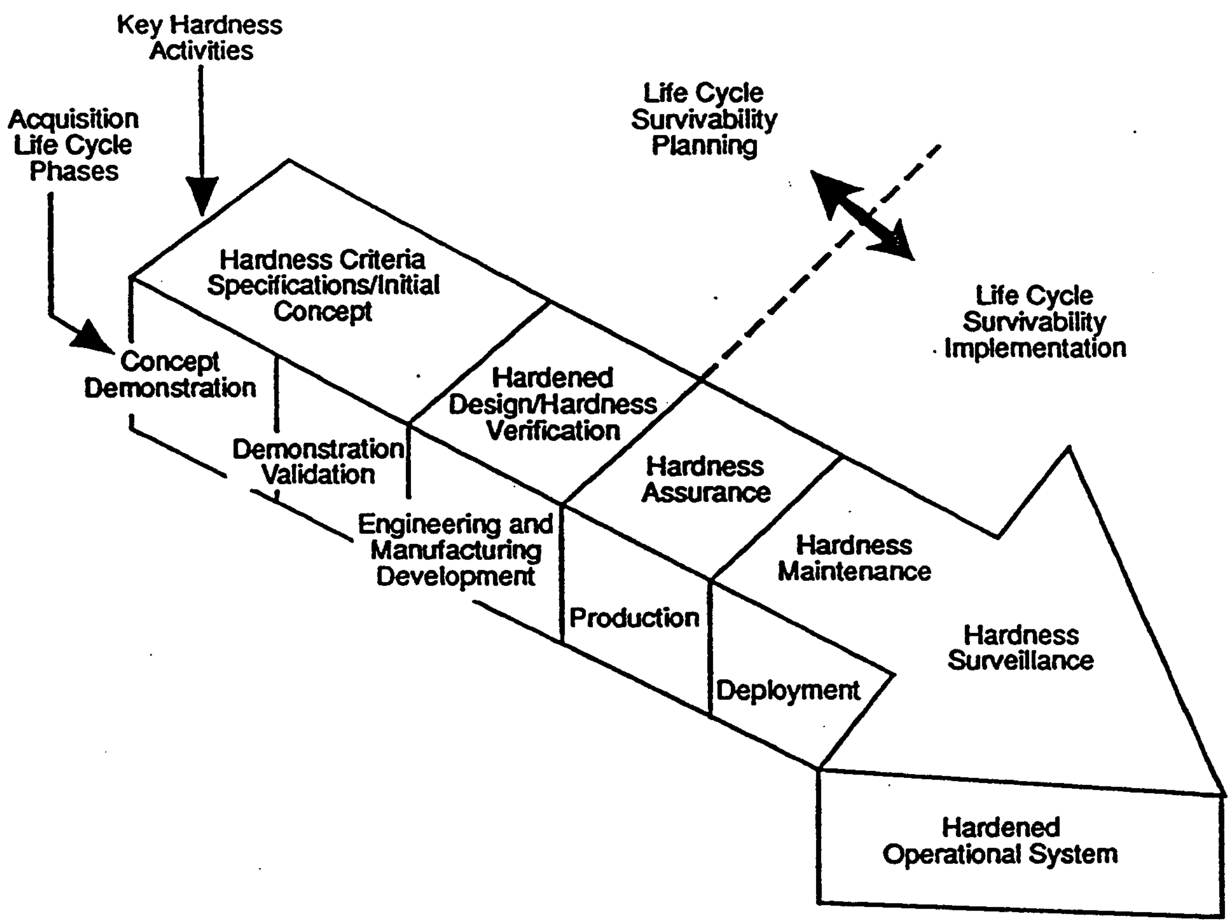

Figure 5-1. Life cycle survivability program.

5.3.1.1 **<u>The CD Phase</u>**. In the Concept Development phase, the environmental specifications, hardness criteria, and initial hardening concepts that match the overall system concept are developed.

5.3.1.2 **<u>The D/V Phase</u>**. During the Demonstration/Validation phase, these items are refined and verified as the system concept is validated. It may include an assessment of the hardness of the preliminary design concepts. Historically, when the demonstration of the system concept was the focus of the Demonstration/Validation (D/V) phase with no attention to survivability, the hardening program suffered or was more costly. Thus, for best results, survivability must be considered early in the Concept Demonstration (CD) phase.

5.3.1.3 **<u>The EMD Phase</u>**. The Engineering and Manufacturing Development (EMD) phase usually requires a large increase in hardening efforts. Detailed design of a hardened system and verification of the design hardness are major activities that require hardening trade studies and piecepart hardness tests.

5.3.1.4 **<u>The Production Phase</u>**. Figure 5-1 shows Hardness Assurance as occurring in the Production phase. In keeping with the definition, HA activities assure production of a system as hard as that verified during EMD in the initial hardened design. It is quickly noted that Figure 5-1 is greatly simplified with emphasis toward survivability. It must be remembered that many other functions necessary for hardening and HA are also occurring during the design phases shown in this figure. To help clarify this point, Figure 5-2 adds hardening and HA considerations along with system development milestones. Notice that these considerations are present from the program initiation and continue throughout the life of the system. As stated in the Scope, it is also necessary to remember that the hardening and HA program must be a part of the overall system development management structure. To emphasize this point, Figure 5-3 gives another perspective of the activities needed in developing a hardened system.

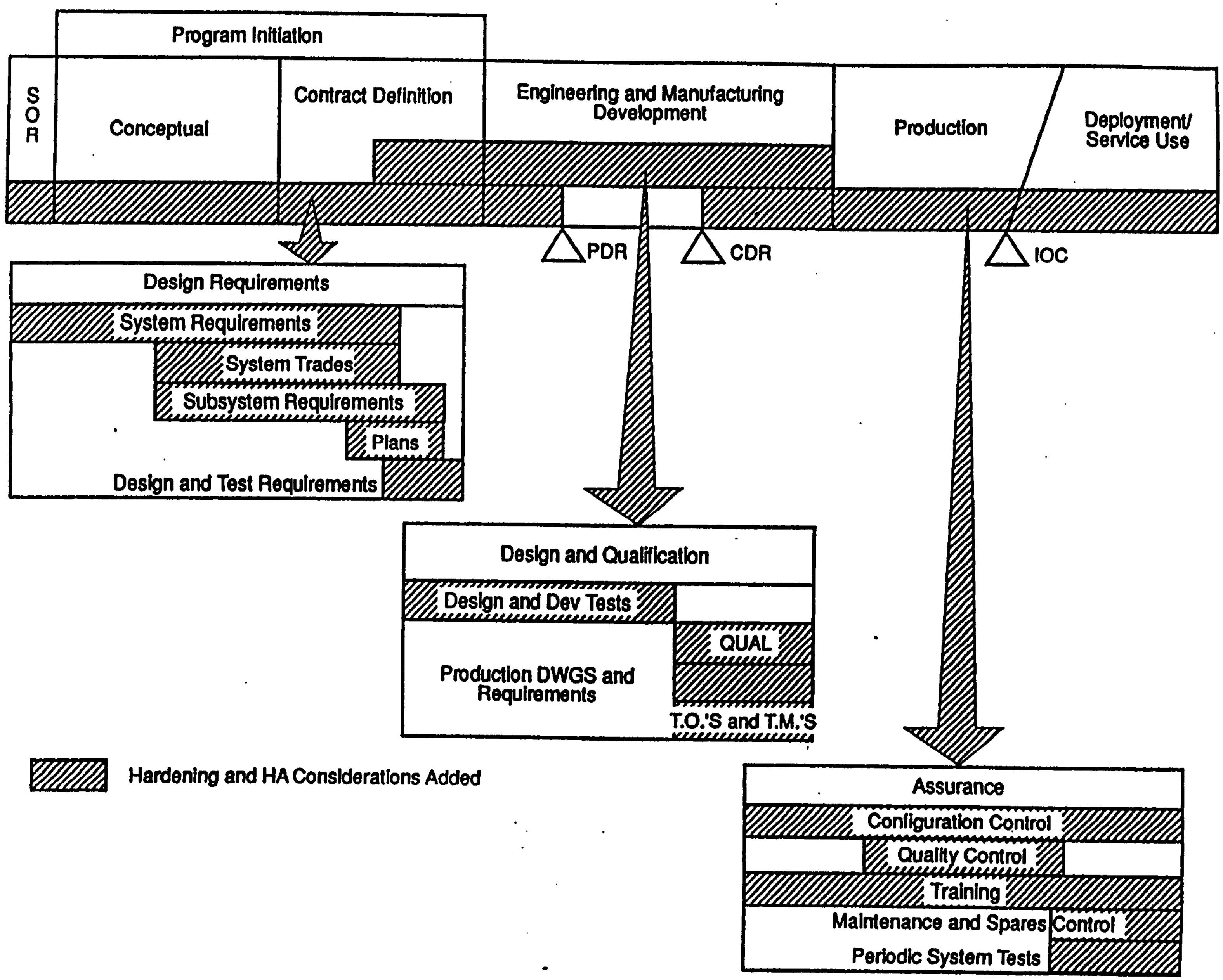

Figure 5-2. Hardening and HA incorporated into normal system development tasks.

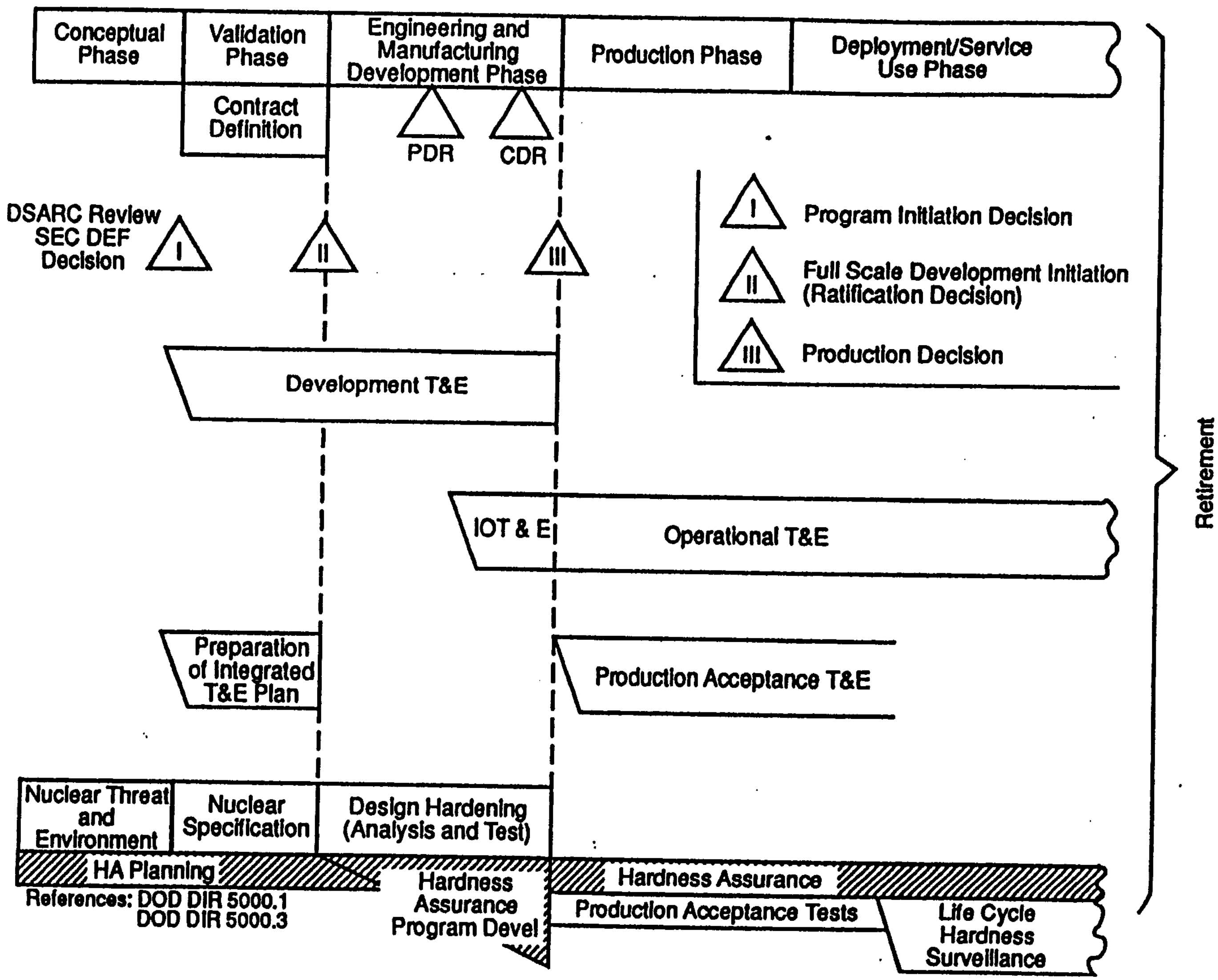

Figure 5-3. The system acquisition life cycle for a hardened system.

5.3.1.5 **<u>The Deployment And Operational Phase</u>.** Finally, during Deployment and Operational use of the system, HM and HS are used to further guarantee the continued hardness of the system once fielded. The HA procedures and controls must apply to the procurement of any repair parts used in HM.

5.4 HA PROGRAM IN LIFE CYCLE SURVIVABILITY.

Hardness Assurance (HA) is a program which is put into action when system production begins. However, before a production phase HA program can be implemented, there must be many HA activities during the design and development phases of system development. These activities include: choosing the correct test and analysis procedures in the selection of technologies and electronic devices needed to satisfy the hardness specification, piece-part characterization and categorization, and formulating a HA plan that is suited to the requirements of the system that is being developed. If the HA plan is not matched to the system requirements, the HA program cannot meet its objectives in the most effective and economical way.

5.4.1 HA in Program Phases.

Considering HA as the product of a continuum of activities is critical. Without proper attention from the beginning of the program, the activity will not be able to successfully assure hardness of the system. Too often, HA is a set of tasks appended to the end of a program to meet a documentation requirement. Without forethought, HA is unlikely to be program or cost effective. In this regard HA is no different than logistics, reliability or a host of other program requirements. As with these other disciplines, HA must be considered in every step of the way. This will happen if HA is treated as the logical product of a series of earlier tasks. The following sections will discuss the details of treating HA throughout the system life cycle.

5.5 PROGRAM MANAGEMENT: DOCUMENTATION OF ROLES.

A typical program will include the appropriate documentation to describe the roles of the contractors and the requirements for action that will result in a proper HA program. Key documents are the Request For Proposal (RFP), the Statement of Work (SOW), and the Contract Data Requirements List (CDRL). These are sponsoring agency documents which may be used to outline agency requirements for a HA program. In these documents, the sponsoring agency should make clear that an effective HA program is both required and expected. A narrative in the RFP and SOW describing the HA program emphasizes the importance of HA. Inclusion of a CDRL item for submission of a HA Program Plan in accordance with the Data Item Description is a minimum requirement. The HA Plan is a contractor document which should be a contract deliverable as well as an item of discussion that requires approval by the sponsoring agency. Such a document should be used to formalize the approach to building and executing the HA program. It should include a discussion of contractor and subcontractor responsibilities, hardness control methods, management approach, and other items pertinent to executing an effective HA program. It is important that the HA Plan be meaningfully reviewed by the agency and then monitored for proper execution.

5.5.1 HA as Part of System Development.

When a radiation survivability requirement is placed on a system, the Project Manager or SPO acquires many survivability-related responsibilities. Once the radiation environments have been specified, the Project Manager must then 1) ascertain that survivability specifications and hardening design rules for the system are developed, 2) see that a hardening program commensurate with the specifications develops in a timely fashion, 3) make certain that a HA program develops as required to assure hardness of the system, and 4) monitor all decisions that impact the cost and schedule of the development of the system, including the HA program.

5.6 GOVERNMENT PROJECT MANAGER (OR SPO) HA ACTIVITIES.

In the development of a system, the Project Manager or SPO will have guidelines as set forth in a number of existing documents such as various DIDs and DoD Dir. 5000.2. This guidance will document the structure of all organizations involved in the endeavor. Included in these documents will be provisions for the formation of the HA program. The actual formation of the HA Plan is usually a designated task for the prime contractor.

5.6.1 Management of HA Activities During Concept Development.

While the CD phase may seem early for consideration of HA activities, this phase is where the HA program must begin. As stated in Section 4.2, it is during CD that the radiation hardness specifications are derived from the radiation environments. Along with the hardness specifications and survivability requirements must come an outline of the HA program. Just as survivability requirements direct design considerations toward important issues, so too does the HA program direct attention to the method of selection and qualification of devices and materials to be used in the CD phase (and perhaps the Demonstration/Validation phase also). In brief, the Project Manager's activities (and those of his staff) during the CD phase must include:

a. the establishment of survivability requirements.

b. the inclusion of system survivability program requirements in RFPs, SOWs, and CDRLs for later phases,

c. the review of contractor-proposed survivability and HA features,

d. the identification of test methods and models and piecepart candidates for the D/V phase.

As the above activities are developed and documented, it is important that the HA program evolves as needed with the test methods and techniques that are available. An example of such an application of HA starting in the CD phase is the use of HA methods available for the evaluation and selection of hardened electronic devices.

5.6.2 Management of HA Activities During the Demonstration/Validation Phase.

At the end of the Demonstration/Validation phase, a complete set of survivability requirements for all items will become available as a result of the verification testing and analyses. Such documentation now provides a basis for control of the hardening design procedures and allows for the completion of HA procedures required during the EMD phase to follow. With completion of the HA program planning, all categories of hardness critical items should be identified and the methods of controlling these items during EMD should be in place and documented. With completion of the survivability plan and HA program, cost estimates and risk areas should also be identified.

5.6.3 Management of HA Activities During EMD.

Activities during EMD are heavily directed at the refinement of survivability features as the hardened and validated design evolves into finality in preparation for production. Review and refinement of designs and test plans are undertaken in order to reduce risks. The HA plan requires the same type of attention during EMD that hardness verification or qualification of the hardware receives. In fact, development of the HA Plan can be effectively managed by tying the plan closely to the Hardness Verification effort. The program manager should encourage and monitor the synthesis of the HA Plan by discussing contractor use of existing hardness data and approved procedures to structure the HA plan. A proposed method to ensure that a comprehensive and effective HA program is generated entails matching the HA controls listed in section 4.1 against verification activities such as testing, analysis, and design. This methodology (matching controls to HA activities) when employed during EMD can engender a variety of Production Phase tasks such as:

a. What controls will be instituted to ensure that the proper shielding (if required) will be correctly installed.

b. What inspections or controls will be instituted to ensure the correct selection and installation of any "special" components required for NH&S.

c. What specific piecepart testing will be implemented to ensure that the calculated design margins will not be compromised.

A complete HA program should also take into account configuration controls, parts and materials controls, and QA/production controls where applicable. These controls tend to be treated as "boilerplate", but they can be critical since they determine how the system is manufactured and fielded.

5.6.3.1 Hardened Parts Control. An outstanding test program does not prevent a contractor from using a soft part; however, proper markings, annotations, and production controls should prevent such an error. The Project Manager must ensure that the contractor's HA Plan contains effective measures to utilize these controls. This leads to perhaps the most critical but least appreciated aspect of a good HA program; plan management and execution. The Project Manager should be satisfied that the HA program provides for effective management and monitoring of the HA process, especially the handling of test failures and other deviations from the hardened baseline design. Table 5-1 presents a basic template to aid in following the HA program activities. The HM/HS plans should also be developed during the EMD phase.

5.6.4 Management of HA Activities During Production.

At the start of the production phase the hardened system design should be complete, and the HA program to ensure system hardness should be in place. As production begins, it will be necessary for the Project Manager to review all procedures and controls related to survivability and hardness assurance to make certain that all parts, especially hardness critical items, are being addressed according to the HA program plan. It will also be necessary to monitor and analyze the results of the HA tests that are being performed. Some of these data will be utilized by the reliability engineers in verifying the probability of survival of the system. For reliability purposes, it will be necessary to continue to document the needed statistical data pertaining to the parts being incorporated into the system. It is crucial that the HA plan requires that any engineering changes made to the system in the production phase must be reviewed by the Configuration Control Board to assure that the survivability of the system is not compromised in any way.

Table 5-1. Program management template for HA.

HA ACTIVITY	PROGRAM MANAGEMENT ACTIVITY
HA Program Management	Ensure creation of HA plan consistent with program requirements, validate that management approach is sufficient to execute plan
HA Design Support	Review hardness design features for impact on HA program and identify test facilities.
HA Tests and Analyses	Ensure adequate analyses and proper testing methods, control of test items and reporting procedures, especially for failures
HA Demonstration and Inspection	Ensure proper procedures, recording and reporting methods
Configuration Management	Identify particular controls and organizational responsibilities for performing each
Parts and Materials Control	Identify particular controls and organizational responsibilities for performing each
Quality Management	Identify particular controls and organizational responsibilities for performing each
Production Controls	Identify particular controls and organizational responsibilities for performing each
HA Training	Review training plan for coverage of key personnel, organizations and adequacy of content relative to HA plan

5.7 CONTRACTOR HA ACTIVITIES.

In a broad sense, it is the role of the system contractor to develop and produce a system which meets all of the requirements imposed by the contract. This task is usually accomplished in concert with a number of sub-contractors for which the contractor must be responsible. In the above discussion of the role of the Project Manager, actions like review, monitor, direct, and ensure are often used to describe the responsibilities of that office. For the system contractor, the major responsibility is to formulate and accomplish the tasks needed to develop the system. For those instances where the system requirements include radiation survivability, one of those tasks to be accomplished is to devise the hardening specifications and the HA program required to ensure that these specifications are maintained through the life cycle of the system. Simply stated, this task often takes the following form:

a. interpret the system survivability requirements relative to the specific system
b. transform these requirements (as given by the Project Manager or SPO) into design specifications (by interpretation of the radiation criteria)
c. incorporate the hardness criteria into the system design
d. verify and document the survivability of the system design
e. formulate a HA plan that will assure survivability through production and the entire life cycle.

Incorporation of survivability into the system design is often referred to as design hardening and occurs in the D/V and EMD phases.

5.7.1 HA During D/V and EMD.

The HA program that must be developed during D/V and EMD involves many production-related aspects. Management of the HA program requires consideration of at least the following topics:

a. interrelationships and responsibilities between organizations such as design groups, survivability engineering, QA, component engineering and procurement
b. hardening design guidelines, including piecepart derating
c. specification interpretation and compliance

d. configuration and parts control

e. quality assurance

f. in-house test procedures and guidelines

g. design margin determination and piecepart categorization

h. parts procurement procedures and acceptance criteria

i. parts and design changes implementation

j. waivers and deviations

k. documentation requirements

l. applications of standards and procedures

m. contingency plans for parts nonavailability

n. incompatible assembly and inspection procedures.

HA controls during the production phase consist primarily of three major concepts. These are:

a. piecepart procurement and acceptance selection controls

b. piecepart usage control.

c. configuration control

5.7.1.1 Parts Control Board. Configuration control consists of those actions and procedures necessary to ensure that no changes are made to the hardened baseline design without proper review and approval; process and parts selection controls are needed to ensure that hardness is not inadvertently compromised during production; and, parts control procedures must be implemented to ensure that the pieceparts are used in conformance with the hardened design. A detailed description of the activities and responsibilities in each of these areas can be found in several references. (Applicable Refs. 17, 33, and 37.) As an illustration, the activities in the parts control area (often performed by a Parts Control Board) are depicted in Figure 5-4. It is such capabilities as those shown here that the contractor must establish and coordinate either in-house or among his sub-contractors.

5.7.2 Documentation of HA Activities.

The depiction of Parts Control Plan as a book in Figure 5-4 is suggestive; there are many aspects of the HA program which must be documented. Depending upon the system function orobjective of the HA procedure, the documents are identified by various names, depending upon the developing organization. Required documentation must be a part of the HA program plan from the beginning.

5.7.3 Use of Existing Standards and Guidelines.

There are a number of existing standards, guidelines, and handbooks available to assist in establishing the HA program and to provide guidance in establishing test plans and procedures. Often, many of these will be invoked contractually by the Project Manager. Many of the documents that are deemed applicable are listed in Section 2 of this document.

5.8 PROGRAM DEVELOPMENT: HA THROUGH ENGINEERING AND MANUFACTURING DEVELOPMENT (EMD).

By the time the system has progressed to EMD, preliminary plans for the HA program should have been made. During EMD the HA program plans should be completed, meaning that all of the inspections, procedures, tests, and other controls must be finalized and all facets of the HA program must be ready for implementation at the beginning of the production phase. There are features common to the development of any HA program: it begins with the radiation environment for the system, whether it is from space radiation, from a nuclear detonation, or both; with these nuclear environments and the mission of the system, the design specifications are then derived to ensure system NH&S; the HA program must then be formulated (as the system develops) to ensure that the system is produced in accordance with the hardened design.

Parts Control Plan Ensures That Variations in Piece-Part Radiation Response Will Not Jeopardize Design Hardness

KEY ELEMENTS

- States Objectives
- Establishes Requirements for Characterization Data
- Describes Piece-Part Test and Analysis Methods
- Details Derating Rules
- Determines Design Margins and Hardness Categories
- Prepares Procurement Specifications
- States HA Controls and Acceptance Test Requirements
- Delineates Responsibilities

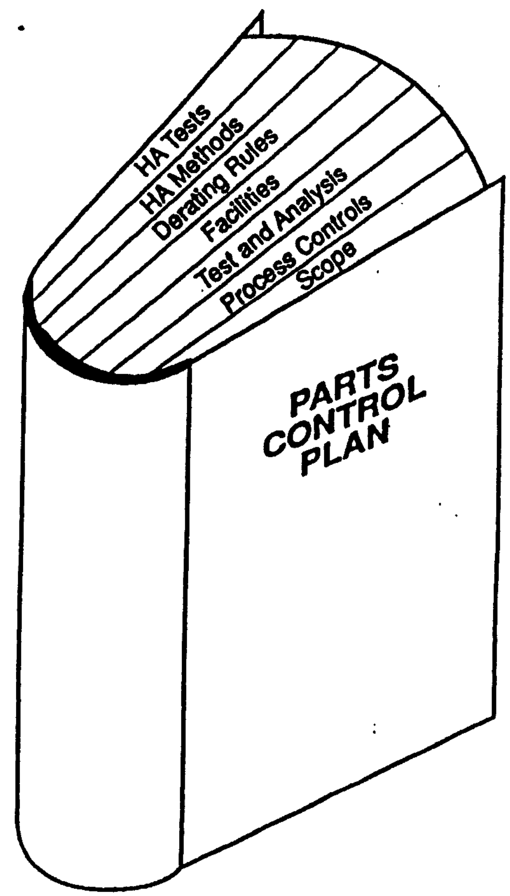

Figure 5-4. Elements of a parts control plan.

5.8.1 Helpful Documents.

For any system that must survive a hostile environment (including nuclear and space radiation), guidelines exist to aid in developing the necessary survivability program. Several such documents are:

1. DoD-STD-1766, "Nuclear Hardness And Survivability Program Requirements For ICBM Weapon Systems."
2. Rose, M., et al, "Design Guidelines For Transient Radiation Effects On Tactical Army Systems," HDL-CR-81-015-1, July 81.
3. Smith, R.A., "Nuclear Survivability For Navy Tactical Systems," NSWC TR-87-58, August 1987.
4. Ferry, J., "Guidelines to Hardness Assurance For Nuclear Radiation, Blast, and Thermal Effects In Systems With Moderate Requirements," AFWL-TR-86-26, February 1987.

5.8.2 HA Role in Piecepart Selection and Qualification.

A key part of the HA program is selecting, qualifying, and controlling pieceparts, especially electronic devices. Because electronic devices play such a major role in performing the necessary functions of the system, and because of their sensitivity to radiation, they are usually the focus of the HA program. A part of meeting the survivability specifications of the system is the selection of electronic devices with the needed design margin. Two documents that can be used in the selection process are MIL-HDBKs-814 and 815. These documents discuss in detail the process of piecepart selection and qualification, including design margins, categorization, and testing issues. The development of specifications for radiation hardness assured devices is covered in MIL-HDBK-816.

5.8.2.1 <u>Use of DMBP and PCC Methods</u>. Depending upon the requirements of the system, either the DMBP or the PCC method or a combination of both methods can be used to determine the RDM in the selection of electronic devices. The DMBP method is usually considered most applicable to systems having low-to-moderate survivability requirements. The PCC method is a fully statistical approach that utilizes variables data (from radiation effects

testing) that leads to the categorization of each piecepart. It can provide a probability of survival P_s, with confidence, C. The PCC method can be used for systems with relatively severe survivability requirements, or to analyze more closely parts that are HCC-1, with the aim of moving them to HCC-2. The DMBP method is an engineering approach that is relatively simple to utilize, basically conservative, but fully adequate for many systems with low radiation survivability requirements. The PCC method, which utilizes single-sided cumulative distribution statistics relative to survivability requirements and sample size, is slightly more difficult to use, but is applicable to any system and provides a sound statistical basis for piecepart survivability estimates. Each method can be applied separately or they can be used in combination. It should be remembered that design hardening and hardness assurance are related in the common goal of producing a system with a specified probability of survival and confidence, P_s + C. This being the case, these activities must be incorporated with all other system reliability considerations for an accurate assessment of the system. For example, the DMBP and PCC methods provide a means for determining the piecepart RDM, thereby allowing the categorization of these parts. It is not the intent of this document to provide a detailed discussion of these methods; instead, it is strongly recommended that MIL-HDBKs-814 and 815 be consulted for a full discussion of these methods and their application. A typical flow chart of the HA activities for pieceparts (or subsystems) is shown in Figure 5-5.

5.8.2.2 **Piecepart Derating.** When pieceparts are eventually designed into circuits and subsystems, one hardening technique that is widely used is the utilization of piecepart derating; i.e., design the circuit so that it still performs its function while using piecepart parameters that assume some degradation from radiation (as well as temperature and aging). While this technique itself may not be an HA issue, the selection of the end-point values allowed after degradation and the techniques required to determine these values relative to the threat should be a part of the HA program plan. It is important to remember that derating factors must be based upon device radiation response data. One method that aids in determining the degree of

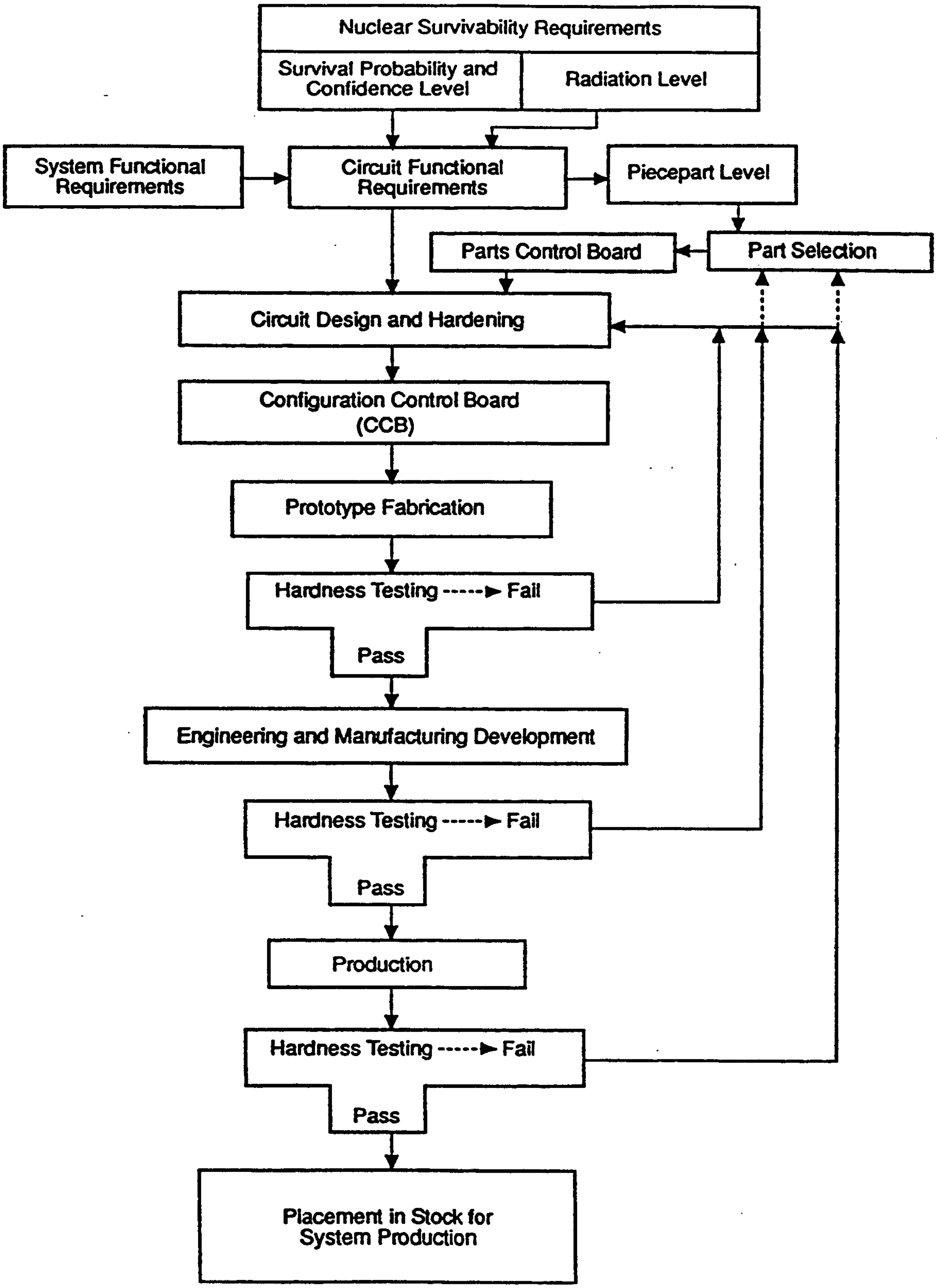

Figure 5-5. Hardness assurance for piece-parts or subsystems.

derating necessary is the use of overtesting. Statistical formulations are available that will enable the determination of sample size required as a function of the overtest factor and the degree of derating (Ref. 32).

5.8.2.3 Test Techniques and Dosimetry Methods. As the complexity of pieceparts has increased with time, so has the challenge of correctly evaluating them in a radiation environment. Take as an example the integrated circuit (IC); the individual elements contained in a VLSIC now number into the millions. To determine that such a device is operating properly and to determine the degradation of its operating parameters as a function of the hostile radiation environment is a challenging task. Fortunately, there are many organizations which have recognized this fact and are working to develop test techniques and guidelines (see Section 2). There are many factors which must be considered when evaluating a VLSIC. Some of these include the technology used, design and fabrication rules, circuit application, device function, relevance of measurements made to usage of the device, and conditions of the test. For some device types, the conditions of the test can greatly influence the results. For example, should the device be irradiated while powered or unpowered? Should functional measurements be made during exposure or should parametric measurements be made following incremental exposures? What is the influence of the operating conditions chosen? What portion of the device is functioning for the measurements being made? While considering all of the these factors, it is important to remember that the primary objective is to develop the most cost-effective method of adequately evaluating the complex integrated circuit of interest. Philosophically, it is necessary to keep test methods as simple as possible. This approach may increase the demands placed upon test planners and the automated testers by increasing the number of test vectors needed and the understanding of how the IC functions so that the test data may be properly interpreted. As devices become more complex, it becomes increasingly more important that the Project Manager ensure that contractors use the accepted test guidelines and standards as much as possible. Utilization of existing guidelines not only makes it possible to use existing data (taken by others), but it also provides a basis for interpreting the data. With the increasing cost of testing, it is important to utilize existing data whenever possible.

It is also important even when using existing guidelines and standards to realize that some aspects of the philosophy of testing must also change as the level of integration of ICs continues to increase. In the case of many VLSICs, it is no longer possible to exercise every element of the device. The cost would be prohibitive; the time to generate the necessary test program (for each device type), the time to do the actual testing and to check and interpret the data can each be very long. The fact that 100 percent of the elements of the device are not tested implies that the level of failure for a given device type has a statistical distribution (within the sample failure distribution). The implications of possible undetected failures, should be a part of the system Failure Mode and Effects Analysis (FMEA) or some similar analysis.

In performing radiation effects tests, accurate dosimetry is very important. The many different sets of nuclear and space radiation criteria sometimes require the experimenter to obtain a complete description of the radiation test environments, perhaps even to tailor it with shielding. There are also times when the energy spectrum is of great importance. There now exist many dosimetry standards that make it possible to have adequate dosimetry for many test situations (see Section 2).

5.8.3 Non Developmental Items.

It should be recognized that many program procurement strategies include use of non-developmental items (NDI). These must be handled somewhat differently than contractor-developed hardware. The Federal Acquisition Regulation (FAR) defines several types of NDI as follows:

a. Commercial Off-The-Shelf (COTS) - Item produced and placed in non-government stock prior to any sale or contract; the item may meet federal or military specifications or description.

b. Commercial-Type Product - A product modified to meet a government-peculiar requirement or identified differently than its normal commercial counterparts.

c. Commercial Product/Best Commercial Practice - The government controlled design includes commercial design practices and commercial parts.

d. Commercial Product/MIL-SPEC Design - Evolved from government/military requirements, not necessarily still needed by the government, but readily available to the general public in normal business operations.

e. Commercial Product/Militarized - Vendor-oriented commercial design for which the military is the primary or only customer.

The use of COTS and Commercial-Type products are difficult to deal with in hardness-required systems since the government has little or no control over details of the internal design and the manufacturer can change it at will. Because of this, typical hardness assurance control mechanisms may be difficult if not impossible to apply. The lack of control over the design of the part certainly makes hardening and hardness assurance more difficult. However, the pressure to reduce program costs is likely to create situations where NDI will be used despite hardness requirements. Accordingly, the use of COTS or similar parts must be carefully approached.

5.8.3.1 <u>HA Activities for NDI</u>. HA choices are constrained if COTS or Commercial-Type products are included in the system. Clearly, it is not possible to choose components of a particular commercial design in an attempt to increase margins. Products appear to require 100% test, inspection or measurement because there are no configuration controls, parts and material controls, no change controls or notices, and no manufacturing controls. Thus, HA of NDI appears quite daunting at first glance. On closer inspection, it may be found that HA strategies are still available for application to NDI. In a commercial market there may be several competing products with different designs. This situation holds out the possibility that there are significant differences in hardness capabilities among the competing designs. If this case does exist, an informed procurement choice is tantamount to developing a harder design and thus providing more design margin.

Choosing a Commercial Part - Once a commercial design is chosen, a major concern surfaces: stability of the design and parts list. Critics often point out that a vendor can change product design at will. While this is true, it ignores the fact that commercial vendors do practice some configuration controls for a variety of practical reasons including manufacturing ease and future maintenance actions. Most vendors maintain parts lists (which may be proprietary), schematics and drawings for each model produced as an aid for manufacturing and for future repair. The vendors know when changes are made and it may be possible to negotiate some type of notification procedure for design changes as long as proprietary information is not compromised. This is really no different than change notification procedures that have been negotiated with semiconductor component vendors on some military programs.

Vendor Help - Vendors typically recognize that planning for future customer support by maintaining technical data and spares is good business. It may even provide increased profits through sales of spare parts or technical services. While such data and parts are not maintained permanently, vendors may be willing to part with proprietary information that has become obsolete. Such an approach by the government to capture a manufacturer's final stocks and design data for HA may be viewed by the vendor as a means of retaining customer goodwill or even generating some final sales of a discontinued model. Such issues and approaches may be negotiable with manufacturers when the original buy is made. In a similar vein, it may be possible to realize HA benefits from internal vendor statistical or process controls. Vendors typically advertise some type of requirements which the equipment will meet. Although a requirement for nuclear radiation hardness is usually not found in commercial equipment, many others such as thermal, shock and vibration specifications may be. In fact, it is not unusual for vendors in some industries where the equipment must be quite rugged to essentially duplicate MIL SPECs. These may necessitate use of high reliability components. This, in turn, may impose requirements on components which are helpful from a HA point of view. As an example, consider electronics which are specified by the vendor to be high reliability hardware. To meet that specification, the vendor may self-impose inspection of transistors for minimum gain or derate nominal electrical parameters by 20%. If such policies are in force, they are of benefit to HA. In short, many standard HA practices may be fortuitously in use by commercial vendors. By carefully investigating commercial hardware choices before procurement, some existing HA-type controls that enhance survivability may be found.

Possible Changes to Commercial Parts - In cases where the above strategies provide no help, NDI will probably need to be modified to meet the hardness requirements. In such cases the modifications will need to be subject to HA controls in the same fashion as any other developmental hardware. A rigorous testing, inspection or measurement program will probably be needed. In these situations, the low cost of procuring NDI needs to be carefully compared against the cost of system hardening (e.g., shielding or more complex HA requirements) and then maintaining the equipment. As an example, some COTS items may be circumvented for survival in a dose rate environment; if the circumvention circuit is added, this change might require design modifications and qualification tests. Most vendors will supply a parts list, circuit diagrams and other necessary information for performing hardness analyses. Such analyses can provide a reasonable estimate of nuclear survivability, and should be a part of the design selection procedures.

5.9 HA DURING PRODUCTION.

The HA program during the production phase must ensure that the hardness of the system that was developed during CD, D/V, and EMD is retained when each system is produced. Hardness of the system could be compromised by the variation in piecepart response or by changes to the hardened design. It is important during the early part of production to check all tests, inspection, and procedures to make certain that all are functioning as intended.

5.9.1 HA Controls and Issues of Concern.

The following controls must be in place at the start of the production phase: (1) the piecepart test data and the survivability analyses that began in the CD phase are available for reference if needed; (2) the approved parts list (APL) has been established; (3) procurement procedures and acceptance tests are in place; and (4) all hardness critical items and processes (HCIs and HCPs) have been appropriately noted for whatever action is necessary. There are general categories of controls and procedures which are utilized to ensure that such items and concerns (as listed) are handled in accordance with the needs of the system. These will be discussed in the following two sub-sections.

5.9.1.1 **Configuration Control.** Configuration control is especially important during the production phase because it is inevitable that changes will occur. Controlling any change is important to system survivability since seemingly insignificant changes in design, process or assembly procedures can adversely affect system hardness.

Configuration Control Board - The organization or body that is typically formed to assess the impact of any change is called the Configuration Control Board (CCB). The CCB is formed to ensure that all changes are subjected to careful examination and receive proper approval prior to implementation. The CCB commonly has approval authority regarding change to the baseline design. For any system with a nuclear survivability requirement, the CCB must contain one or more nuclear survivability specialists with the ability to judge whether a proposed change may degrade the survivability of the system. A typical diagram of CCB activities is depicted in Figure 5-6, showing the organizations with which the CCB should interface. Guidance concerning configuration change controls is also available in MIL-STD-480. Depending upon the situation, there may be other applicable guidance documents also (see Section 2). Some aspects of the CCB include: (1) A person or group involved with piecepart control; this group may be called a Piecepart Control Board, and (2) piecepart control which will require as a minimum some type of procurement control. Depending upon the requirements, these controls may range from procurement under established specifications or it may involve stringent source control with lot acceptance testing and possible screening of parts. This group serves an important function in light of the fact that electronic devices play a major role in all systems.

5.9.1.2 **Engineering Change Proposal.** This document--or its equivalent by some other name--is the vehicle for initiating design changes to the system. It is important because it necessitates the documentation of the proposed change which then allows the CCB to act upon it.

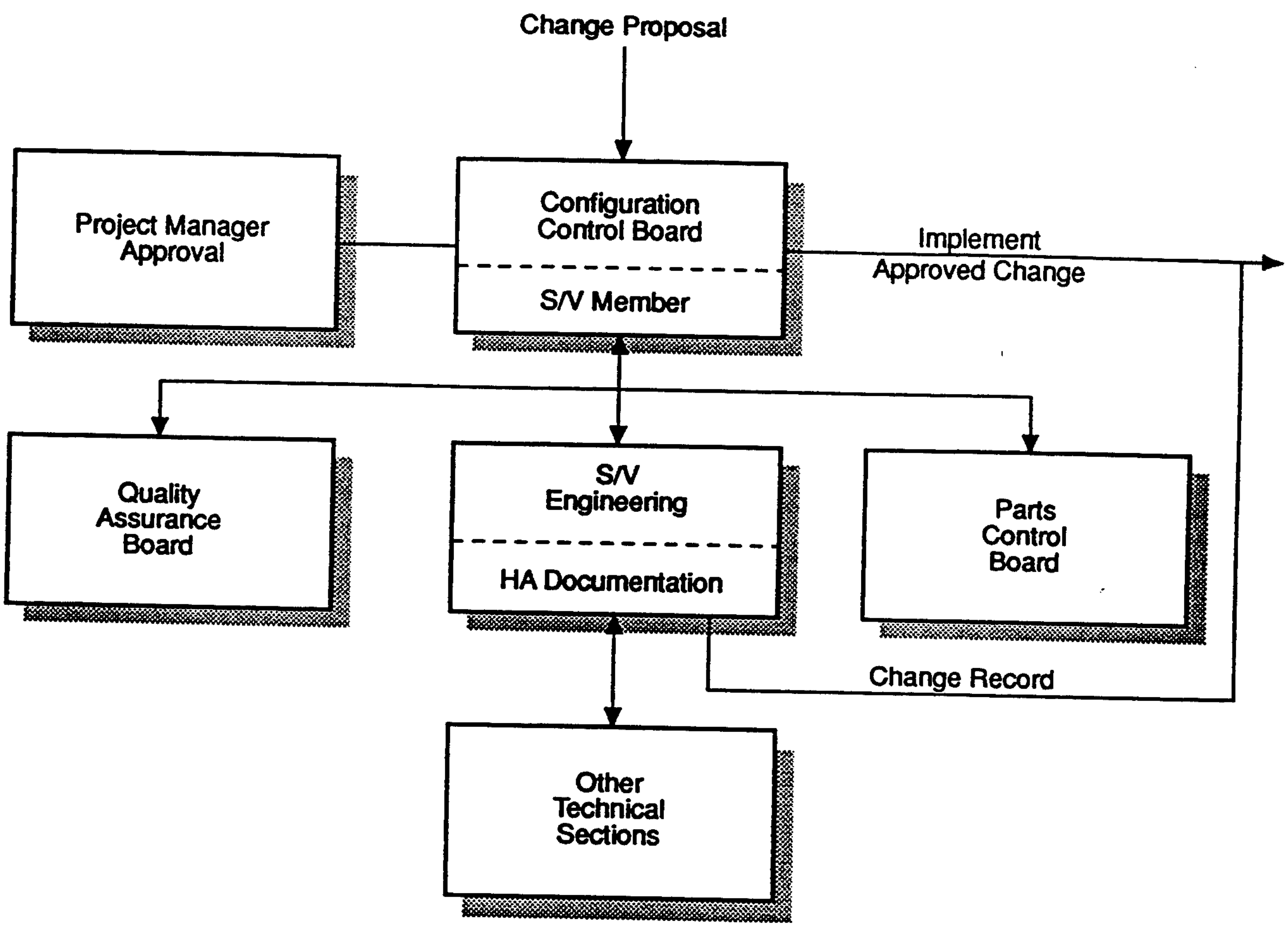

Figure 5-6. Typical configuration control board flow chart.

5.9.2 Quality Assurance.

Some quality assurance (QA) procedures are related to system nuclear survivability. These survivability-related quality assurance (QA) procedures are designed to ensure that production items conform to the hardened design. Hardness-related QA should be the result of cooperative efforts by a number of organizations including the survivability and production personnel. This cooperative effort should produce documented procedures that specify the required inspections and tests. The identification of hardness critical items (HCI), processes, and procedures is necessary. Hardness critical items and processes will be identified as part of the HA program. This process is discussed in DoD-STD-100. An important part of this process is the requirement that any HCI, process, procedure or related work instruction not be changed in any way without undergoing the specified review and approval procedure. The gathering of cumulative statistics (on pieceparts) from sampling and testing provides needed data for reliability assessments and for improving the estimated hardened capability of the system.

5.9.2.1 **Procurement Procedures.** Procurement of pieceparts for a system will involve a wide variety of procedures and must be coordinated for production. Attention is immediately focused on hardness critical items and the precautions that must be taken to ensure that their response remains acceptable. Parts available on a standard military drawing (SMD) are under some degree of manufacturing control. Source or specification control drawings may be required for some parts. Some variations in procurement practices that may be necessary range from the "one-time buy" to that of managing a "captive line" of the manufacturer of the piecepart of interest. The availability of radiation hardness assured devices should be ascertained. Long lead-time procurements have to be identified early enough to avoid interruption of the production schedule.

5.9.2.2 **Pieceparts Categorization**. Prior to the Production phase, all pieceparts should have been categorized. This categorization is necessary to keep acceptance testing costs to a minimum. Through determination of the Radiation Design Margin (RDM), all parts will fall into one of the broad categories as follows:

a. Unacceptable: The RDM is so small that the parts are judged unacceptable for use in the system.

b. HCC-1: The RDM for these parts is such that some sort of HA control on every purchase is needed.

c. HCC-2: These parts have a relatively large RDM, but still require periodic tests of each supplier to assure that the hardness has not changed.

d. HNC: The RDM for these parts is sufficiently large that no acceptance or periodic testing is needed.

Clearly, it is of benefit to the program to have as many of the parts as possible in the HNC and HCC-2 categories.

5.9.2.3 **Piecepart Acceptance Testing.** Essentially every part in the production process will have some sort of acceptance criterion as discussed above. The acceptance requirements may range from simple visual inspections to destructive lot sample testing. As mentioned previously, much attention may be required by the electronic devices. Often some of these are in the HCI category and may require special attention. Rigorous acceptance testing to meet the radiation requirements for HCI is necessary. Such testing could include lot acceptance tests for both ionizing dose and neutron exposure. Some systems also implement 100 percent latchup screening as well as dose rate upset testing for parts associated with circumvention circuitry.

5.9.2.4 **Compatibility with Furnished Equipment.** In the development of some systems, it is possible that some of the parts will be furnished by the developer; e.g., government furnished equipment (GFE). This category could also include non-developmental items (NDI). In both instances, consideration must be given to the acceptance procedures that are required whether it be inspection, extensive check-out, or some form of testing and analysis. These considerations must be a part of the HA/QA program so that the production flow is not disturbed.

5.9.3 How HA Leads to HM/HS.

Once a system has been produced with assurance that it is hardened as specified, precautions must then be established to ensure that this hardness capability is not jeopardized by subsequent activities during the operational life of the system. As defined in Section 1 of this document, it is the Hardness Maintenance (HM) and Hardness Surveillance (HS) programs which have as their objectives the prevention of compromise of the hardness of a system during its operational life. There are two aspects of HM/HS that must be considered; operational maintenance and balanced hardness. To illustrate, it is quite easy to compromise the hardness to nuclear radiation during routine maintenance by substituting soft electronic devices for those that are radiation resistant (even though electrical characteristics might be the same). This type of problem can be avoided with the development of proper maintenance procedures stated in drawings and technical manuals. But there are other forms of compromise that are perhaps more subtle; this involves compromise of the system to threats such as SGEMP, IEMP, HPM or EMP while exercising great care with respect to neutrons and gammas. For example, improper replacement of a cover during routine maintenance could compromise the EM hardening of that item. It is therefore seen from this illustration that with the concept of balanced hardening, HA controls and procedures must be included in the HM/HS programs throughout the entire operational life of a hardened system.

5.9.4 HA Documentation.

As noted throughout this document, many references are made to the importance of documenting the HA program and those data that result from the HA activities. The importance of such documentation cannot be over stressed, but it should be noted that all systems do not require the same documentation. For instance, a system with a relatively low radiation requirement may utilize the Nuclear Survivability Design Parameters Report (NSDPR), the Nuclear Survivability/Vulnerability Plan (NS/VP), the HM/HS Plan, or some combination of these documents as required. On the other hand, for a system that is more complex or has more demanding radiation survivability requirements, the development contract usually has as a requirement the formation of a Hardness Assurance Program Plan (HAPP). The format and perspective of the HAPP is covered in Data Item Description (DID) DI-NUOR-80926.

5.9.4.1 <u>Data Item Descriptions</u>. A certain number of DIDs are essential in developing a Hardness Assurance program. Table 5-2 shows a listing of current DIDs. These documents are important because they describe the format and content of various reports, plans, and listings which are CDRL deliverables for a contract with nuclear hardness requirements. The Statement of Work must call out CDRL items with these DIDs to ensure receipt of the proper data for hardness documentation. When choosing a DID for CDRL definition, it is important to verify that the DID will identify the data needed and properly serve the intended use. Several of the DIDs are program specific. For example, DID-M-30412 refers to documents written expressly for the Minuteman program. It may not be applicable for use by other programs. Most of the other DIDs are more general, and, in fact, there is overlap between them. The DI-ENVR series was written primarily for ICBM systems, but is general enough in requirements and format that it could be used in other applications. The DI-NUOR series is general enough to be used in all cases except where very specific and unusual requirements exist. Two of the DIDs are so general that the word "nuclear" does not occur in their titles. DID-R-21482 and DID-MISC-80565 are written to cover any type of survivability effort, but the text of these DIDs do explicitly call out nuclear survivability as possible applications. DID-ILSS-81161 is unusual in that it is limited to simply providing a Hardness Critical Item (HCI) list for insertion into Logistics Support Analysis Data Records. Considering that Hardness Maintenance is a key part of life cycle hardness, this DID is very useful and important. A current listing of DIDs is contained in DoD 5010.12-L, the Acquisition Management System and Data Requirements Control List (AMSDL).

5.9.4.2 <u>Hardness Assurance Design Document</u>. This document has been used by the Air Force on several programs. It is a collection of HA related information and is tailored somewhat to the system mission and requirements. There is a suggested format (Ref. 17) that includes four volumes. These are: Volume I - an Introduction; Volume II - a listing of all HCIs and HCPs; Volume III -the HA Program Plan, and Volume IV - all HA related analyses.

Table 5-2. Current Data Item Description (DIDS).

NUMBER	TITLE	ORIGI-NATING AGENCY	USE
DI-NUOR-80156A	NUCLEAR SURVIVABILITY PROGRAM PLAN	ARMY	GENERAL
DI-NUOR-80926	NUCLEAR SURVIVABILITY ASSURANCE PLAN	ARMY	GENERAL
DI-NUOR-80927	NUCLEAR SURVIVABILITY DESIGN PARAMETERS REPORT	ARMY	GENERAL
DI-NUOR-80928	NUCLEAR SURVIVABILITY TEST PLAN	ARMY	GENERAL
DI-NUOR-80929	NUCLEAR SURVIVABILITY TEST REPORT	ARMY	GENERAL
DI-NUOR-81025	NUCLEAR SURVIVABILITY MAINTENANCE/SURVEILLANCE PLAN	ARMY	GENERAL
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DI-ENVR-80387	TRANSIENT RADIATION EFFECTS ON ELECTRONICS HARDENING PLAN	AF	GENERAL
DI-T-5317	NUCLEAR EFFECTS TEST PLAN	NSA	PRIMARILY COMSEC
DI-T-5456	HARDNESS ASSURANCE PROGRAM PLAN	NSA	PRIMARILY COMSEC
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DI-T-5459	NUCLEAR SURVIVABILITY FINAL REPORT	NSA	PRIMARILY COMSEC
DI-MISC-80565	SURVIVABILITY PROGRAM PLAN	AF	GENERAL
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DI-R-21482A	VULNERABILITY ASSESSMENT REPORT	NAVY	GENERAL
DI-M-30412A	HARDNESS DATA MANUAL MAINTENANCE DOCUMENT	AF	MINUTEMAN
DI-S-3630	NUCLEAR HARDNESS MAINTENANCE AND SURVEILLANCE PROGRAM PLAN	AF	MINUTEMAN MX

Volume I, The Introduction.--This volume should include descriptions of the operational features of the system. It should give a configuration of the system, an identification of all subsystems, and the hardening approach taken in meeting the survivability specifications. In addition, it could include all special items that need to be remembered for production, and identify the availability of classified material if it is necessary.

Volume II, The HCI Listing.--This volume should provide a listing of all HC parts and processes within the system. It should further identify where these HC parts are used, their HC category, and why they are HC parts. It should also contain any special information required for the proper utilization of each of these parts.

Volume III, The HA Plan.--This volume presents the management and organizational plan for implementing the HA objectives during the production phase. Specific details should be included on the relationships and responsibilities of all contractors and organizations that are involved. Full details should be provided in this plan for production controls, inspections, and tests. A contingency plan should also be formulated to address potential production stoppages resulting from such events as design changes, nonavailability of parts, or QC failures.

Volume IV, Analyses.--This volume is intended to provide a known location for all analyses pertinent to survivability and hardness assurance. This information is considered to be significant to the hardened baseline design and therefore a possible aid during production and the life cycle of the system. Volume IV may contain many sections; e.g., one for TREE analyses, one for thermal analyses, one for ionizing dose effects, and so on. Numbering and control of these sections should allow easy identification and access to all categories of information. It should be noted that these analyses, along with all subsequent test data, become an important part of any HA program and are essential for the proper evaluation of any proposed design changes as input to the Configuration Control Board.

5.10 OTHER HARDNESS ASSURANCE CONSIDERATIONS: STATISTICAL.

In previous sections, we have alluded to the fact that any system with a survivability requirement must be allocated a portion of the failure budget in computing the probability of system survivability with confidence, $P_s + C$. The system HA/reliability model that is utilized to calculate $P_s + C$ can be used in other important areas also; e.g., the impact of high risk items and the planning of HA costs. Use of the HA model can be useful to both the Project Manager and to the prime contractor in examining and planning various aspects of the system throughout its entire life cycle. This model must consider failure probabilities at all levels of integration; pieceparts through major subsystems.

5.10.1 Piecepart or Lower-Tier Elements.

System level survivability cannot be separated from the hardening and hardness assurance consideration of pieceparts (devices) and lower-tier elements of the system. The statistical consideration of pieceparts enters the HA/reliability model in two ways: 1) the failure data gathered for pieceparts is statistically valid because a sufficient quantity of parts can be tested at this low-tiered level; and, 2) the influence of pieceparts on system-level survivability can be assessed for high risk as well as parts with large design margins. Both aspects are important since pieceparts (electronic devices) play a major role in the operation of the system and knowledge of piecepart design margins helps in planning a cost-effective HA program. The latter point is of special concern to HA because it allows a focus of attention on "critical" items and a relaxation of HA focus on items with large design margins.

5.10.2 Optimization of HA Cost.

Any HA program costs something, and it is recognized that cost is of paramount importance in the development and production of every system. The HA program is there for the purpose of ensuring the production and deployment of a reliably and adequately hardened system that meets all of the survivability requirements at a minimal cost. The HA program should then be viewed as a tool that is used to develop and produce a system in the most cost-effective manner. Once the HA program has been described, it is appropriate to use every means available to assess the cost as part of the system development cost. One aid in making this assessment is use of the HA/reliability model already mentioned. Another method to aid in minimizing HA cost is a selective allocation of hardness assurance effort by means of a failure budget.

5.10.2.1 Failure Budget Concerns. Failure budget is another of those terms whose definition is not unanimously accepted throughout the HA community. It is usually defined statistically as that part of the allowable probability of system failure, P_f (with $P_f = 1 - P_s$), that is assigned to survivability. Once survivability has been allocated its portion of the failure budget - say 25 percent, for example - then it must be determined how this budget will be distributed among the various elements that influence system survivability. One commonly used practice is to divide the allowed percentage among the system, sub-systems, and components. Once this is done, further allocations are made for specific portions of the radiation environment. The radiation environments usually considered are ionizing dose, neutron fluence, ionizing dose rate, and single event effects (SEE). Once these environments have been ranked in importance for the system, then an allocation can be made. As an example, for a space system, most of the budget would go to ionizing dose with the next largest allocation going to SEE. Neutron fluence and prompt dose rate might be trivial in importance. For tactical ground systems, the allocation would be split between ionizing dose, neutron fluence, and dose rate with SEE getting none. Usually, MOS technologies*** receive no allocation for neutron fluence. The determination of these allocations may be an iterative process that occurs during the early phases of system development. This process may be viewed as one of the techniques that ensures that available HA funds are expended in areas of high risk and uncertainty as opposed to areas dealing with much lower failure probabilities. Careful consideration of the failure budget leads to a better focused and more cost-effective HA program. To perform the formidable task of establishing a survival failure budget early in the system development program (as it should be) requires

***Possible exceptions are charge control devices, some classes of power transistors, and BICMOS devices.

expertise in the survivability areas and related analyses. The budget established by analysis and expert opinion should be updated as the program develops.

5.10.2.2 <u>Emphasis on Hardness Critical Items</u>. As we have discussed the survivability failure budget above and hardness critical categories in Section 5.8.2.1, it should be obvious that a prime intent of the HA program is to focus a large portion of the HA activities on the hardness-critical items and processes within the system. This philosophy has been found to yield the most effective results.

5.10.3 Design Margin Considerations.

In previous sections, the terms design margin (DM) and radiation design margin (RDM) have been used both in the context of circuit design rules and in the determination of hardness critical categories. Often these terms - DM and RDM - have been used synonymously, although it is the RDM which is meant. The RDM is defined as the ratio of the mean radiation level at which the test sample of pieceparts reaches a predetermined failure point, to the radiation specification level. Expressed in equation form,

$$RDM = \frac{\phi_{Mean\,Fail.}}{\phi_{spec.}}$$

It is commonly accepted that the failure distribution for devices in radiation is log normal. This being the case, the mean failure would be a geometric mean value. For further details on the RDM, including the definition and use of the standard deviation of failure distributions, see MIL-HDBKs-814 and 815. Because the DM concept is often interpreted and applied incorrectly, it is incumbent upon the Project Manager or SPO to make certain that the definition of DM is clear and that its application to the system is clearly understood by the prime contractor and all others involved.

5.10.3.1 Avoiding Multiple Design Margins. As a system develops, various organizations have the opportunity to invoke a DM to help ensure a "conservative" approach to system survivability. This is a simplistic approach to HA that could wind up being either costly or risky. Furthermore, this approach can compound. An example of how multiple design margins could occur might go as follows. For a system with a radiation survivability requirements, a criteria organization has to define the radiation environments that the system must survive. To cover the uncertainty or worst case for the mission, this group may over-specify the threat, thereby invoking some safety factor or design margin (DM_1). When this requirement is passed on to the Project Manager, the PM may invoke another design margin with the rationale that this (DM_2) would ensure the survival of the system against the specified threat. Again, the radiation specifications are effectively raised to a more difficult level. When the Project Manager (sponsoring agency) passes these radiation specifications on to the system developer (prime contractor), this organization may impose yet another design margin (DM_3) and safety factor when they select the technology to be used in the system. If this type of scenario is allowed to happen, it can be seen that the system developer may well be working to a radiation specification that could be an order of magnitude or more higher than is really necessary. These inadvertent applications of DMs results in excessive survivability criteria and a subsequent HA program that is excessively demanding and therefore much more costly than necessary.

5.10.3.2 Precautions Against Over-Specifying. As a precaution against over-specifying and thereby making the system more difficult and more costly to develop, the survivability specification should be well understood both in origin and intent. It is never enough to simply accept specifications without any consideration of whether or not they are realistic relative to the mission of the system. An analysis of the environments and related specifications is in order in the CD phase. Care must also be exercised regarding this analysis to ensure that the person (or group) that performs it possesses the expertise to evaluate the specifications against the mission of the system with full consideration of the tactical employment. Once this fact is established to the satisfaction of the Project Manager, an appropriate hardening and hardness assurance program can be implemented on a sound engineering basis.

APENDIX A

LIST OF TERMS

Configuration Control	Activities and procedures necessary to ensure that no changes are made to the hardened design without proper review and approval.
Design Hardening	The design techniques and approaches applied to increase the system survivability.
Design Margin	The ratio of the mean failure level of a piecepart to the specification value. This can be expressed as the ratio of either radiation environment levels or parametric values.
Hardness	A measure of the ability of a system or piecepart to withstand exposure to one or more effects of man-made hostile environments.
Hardness Critical Category	Hardness categories used to classify parts relative to their sensitivity to the radiation environment.
Hardness Critical Item	Any item at any assembly level which could be designed, repaired, manufactured, installed, maintained or removed for normal operation but could degrade system survivability in a nuclear environment if hardness requirements are not considered.
Hardness Critical Process	Processes, specifications and procedures which are hardness critical, and which, if changed, could degrade nuclear hardness.
Hardness Dedicated Item	An item that is dedicated to achieving the required hardness of the system. The item usually serves no other purpose and is nonfunctional except in response to a nuclear weapon environment.
Hi-Rel	A term which describes high reliability pieceparts and manufacturing processes in which the yield is high and the manufacturing process is "perfected" or "mature." The term

generally applies to an approved manufacturer's high reliability program.

Life Cycle Survivability	Procedures to ensure that a system will meet or exceed the required nuclear-weapon-effects specifications through the production and operational phases of the system.
Mission Critical	Elements of the system (e.g., subsystems and modules) which are necessary to mission completion.
Parts	The lowest tier elements of the design. Parts includes the subcategories components and pieceparts.
Pieceparts	Electrical and electronic parts.
Race Conditions	Timing conditions that can be associated with circumvention circuitry and take into account the "race" or arrival times of two signals at an equivalent summing junction.
Survivability	The capability of a system to avoid or to withstand hostile environments without suffering an abortive impairment of its ability to accomplish its designated mission.
Vulnerability	The characteristics of a system which cause it to suffer a definite degradation (reduced capability to perform the designated mission) as a result of having been subjected to a hostile environment.

APPENDIX B

LIST OF ACRONYMS

ALCM	Air Launched Cruise Missile
ASIC	Application Specific Integrated Circuit
C	Confidence Level
CCB	Configuration Control Board
CD	Concept Development
CDR	Critical Design Review
CDRL	Contract Data Requirements List
COTS	Commercial-Off-The-Shelf
CS	Concept Studies
DESC	Defense Electronic Supply Center
DI	Dielectrically Isolated
DID	Data Item Description
DM	Design Margin
DMBP	Design Margin Breakpoint
DOC	Demonstration of Compliance
DSARC	Defense System Acquisition Review Committee
D/V	Demonstration/Validation (also Design/Verification)
ECEMP	Electron Caused EMP
EDAC	Error Detection And Correction
EMD	Engineering And Manufacturing Development (also called FSED and FSD)
EMP	Electromagnetic Pulse
ERRIC	Electronics Radiation Response Information Center
FXR	Flash X-Ray
GFE	Government Furnished Equipment
HA	Hardness Assurance
HADD	Hardness Assurance Design Documentation

HAMS	Hardness Assurance Monitoring System
HC	Hardness Critical
HCC	Hardness Critical Category
HCI	Hardness Critical Item
HCP	Hardness Critical Process or Procedure
HDI	Hardness Dedicated Item
HEMP	High Altitude EMP
Hi-Rel	High-Reliability
HM	Hardness Maintenance
HNC	Hardness Non-Critical
HS	Hardness Surveillance
IC	Integrated Circuit
IEMP	Internal EMP
IOC	Initial Operational Capability
IOT&E	Initial Operation Test and Evaluation
JEDEC	Joint Electronic Device Engineering Council
JI	Junction Isolated
LCS	Life Cycle Survivability
LINAC	Linear Accelerator
LSI	Large Scale Integrated (Circuit)
LTPD	Lot Tolerance Percent Defective
MC	Mission Completion or Mission Critical
MHDEMP	Magneto Hydrodynamic EMP
MIL-STD	Military Standard
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MSI	Medium Scale Integrated (Circuit)
NDI	Non-Developmental Item
NH&S	Nuclear Hardness and Survivability
NSN	National Stock Number
O&M	Operation and Maintenance

OP-AMP	Operational Amplifier
PCB	Parts Control Board
PCC	Parts Categorization Criterion
PDR	Preliminary Design Review
PIDS	Prime Item Development Specification
PMRT	Program Management Responsibility Transfer
PPSL	Program Parts Selection List
Ps	Probability of Survival
QA	Quality Assurance
QAB	Quality Assurance Board
QML	Qualified Manufacturer's List
QPL	Qualified Parts List
RDM	Radiation Design Margin
RFP	Request for Procurement
RHA	Radiation Hardness Assurance
SCD	Source or Specification Control Drawing
SCR	Silicon Controlled Rectifier
SDE	Silicon Damage Equivalence
SEBO	Single Event Burn-Out
SEE	Single Event Effects
SEL	Single Event Latchup
SEP	Single Event Phenomenon
SEU	Single Event Upset
SGEMP	System Generated EMP
SID	Selected Item Drawing
SMD	Standard Military Drawing
SOI	Silicon On Insulator
SOR	System Operational Requirements
SOS	Silicon On Sapphire
SOW	Statement of Work

SPEC	Specification
SPO	Systems Program Office
SREMP	Source Region EMP
S/V	Survivability/Vulnerability
SVWG	Survivability/Vulnerability Working Group
TM	Technical Manual
T.O.	Technical Order
TQM	Total Quality Management
TREE	Transient Radiation Effects on Electronics
TTL	Transistor-Transistor Logic
VA/VR	Vulnerability Analysis/Verification Report
VLSIC	Very Large Scale Integrated Circuit

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