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MULTICS SECURITY EVALUATION

VULNERABILITY ANALYSIS

ELECTRONIC SYSTEMS DIVISION

JUNE 1974

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A security evaluation of Multics for potential use as a two-level (Secret/Top Secret) system in the Air Force Data Services Center (AFDSC) is presented. An overview is provided of the present implementation of the Multics Security controls. The report then details the results of a penetration exercise of Multics on the HIS 645 computer. In addition, preliminary results of a penetration exercise of Multics on the new HIS 6180 computer are presented. The report concludes that Multics as implemented today is not
(Con't on reverse)

19. KEY WORDS

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Virtual Memory

20. ABSTRACT

certifiably secure and cannot be used in an open use multi-level system. However, the Multics security design principles are significantly better than other contemporary systems. Thus, Multics as implemented today, can be used in a benign Secret/Top Secret environment. In addition, Multics forms a base from which a certifiably secure open use multi-level system can be developed.

PREFACE

This is Volume II of a 4 volume report prepared for the Air Force Data Services Center (AFDSC) by the Information Systems Technology Applications Office, Deputy for Command and Management Systems, Electronic Systems Division (ESD/MCI). The entire report represents an evaluation and recommendation of the Honeywell Multics system carried out under Air Force Project 6917 from March 1972 to June 1973. Work proceeding after June 1973 is briefly summarized. Work described in this volume was performed by personnel at ESD/MCI with support from the MITRE Corporation. Computer facilities at the Rome Air Development Center and the Massachusetts Institute of Technology were used in the evaluation effort.

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References in parentheses (2) are to footnotes. References in angle brackets <AND73> are to other documents listed at the end of this report.

SECTION I

INTRODUCTION

1.1 Status of Multi-Level Security

A major problem with computing systems in the military today is the lack of effective multi-level security controls. The term multi-level security controls means, in the most general case, those controls needed to process several levels of classified material from unclassified through compartmented top secret in a multi-processing multi-user computer system with simultaneous access to the system by users with differing levels of clearances. The lack of such effective controls in all of today's computer operating systems has led the military to operate computers in a closed environment in which systems are dedicated to the highest level of classified material and all users are required to be cleared to that level. Systems may be changed from level to level, but only after going through very time consuming clearing operations on all devices in the system. Such dedicated systems result in extremely inefficient equipment and manpower utilization and have often resulted in the acquisition of much more hardware than would otherwise be necessary. In addition, many operationai requirements cannot be met by dedicated systems because of the lack of information sharing. It has been estimated by the Electronic Systems Division (ESD) sponsored Computer Security Technology Panel <AND73> that these additional costs may amount to $100,000,000 per year for the Air Force alone.

1.2 Requirement for Multics Security Evaluation

This evaluation of the security of the Multics system was performed under Project 6917, Program Element 64708F to meet the requirements of the Air Force Data Services Center (AFDSC). AFDSC must provide responsive interactive time-shared computer services to users within the Pentagon at all classification levels from unclassified to top secret. AFDSC in particular did not wish to incur the expense of multiple computer systems nor the expense of encryption devices for remote terminals which would otherwise be processing only unclassified material. In a separate study completed in February 1972, the Information Systems Technology Applications Office, Electronic Systems Division (ESD/MCI) identified the Honeywell Multics system as a candidate to meet both

AFDSC's multi-level security requirements and highly responsive advanced interactive time-sharing requirements.

1.3 Technical Requirements for Multi-Level Security

The ESD-sponsored Computer Security Technology Planning Study <AND73> outlined the security weaknesses of present day computer systems and proposed a development plan to provide solutions based on current technology. A brief summary of the findings of the panel follows.

1.3.1 Insecurity of Current Systems

The internal controls of current computers repeatedly have been shown insecure through numerous penetration exercises on such systems as GCOS <AND71>, WWMCCS GCOS <ING73, JTSA73>, and IBM OS/360/370 <GOH72>. This insecurity is a fundamental weakness of contemporary operating systems and cannot be corrected by "patches", "fix-ups", or "add-ons" to those systems. Rather, a fundamental reimplementation using an integrated hardware/software design which considers security as a fundamental requirement is necessary. In particular, steps must be taken to ensure the correctness of the security related portions of the operating system. It is not sufficient to use a team of experts to "test" the security controls of a system. Such a "tiger team" can only show the existence of vulnerabilities but cannot prove their non-existence.

Unfortunately, the managers of successfully penetrated computer systems are very reluctant to permit release of the details of the penetrations. Thus, most reports of penetrations have severe (and often unjustified) distribution restrictions leaving very few documents in the public domain. Concealment of such penetrations does nothing to deter a sophisticated penetrator and can in fact impede technical interchange and delay the development of a proper solution. A system which contains vulnerabilities cannot be protected by keeping those vulnerabilities secret. It can only be protected by the constraining of physical access to the system.

1.3.2 Reference Monitor Concept

The ESD Computer Security Technology Panel introduced the concept of a "reference monitor". This reference monitor is that hardware/software combination which must monitor all references by any program to any data anywhere in the system to ensure that the security rules are followed. Three conditions must be met to ensure the security of a system based on a reference monitor.

a. The monitor must be tamper proof.

b. The monitor must be invoked for *every* reference to data anywhere in the system.

c. The monitor must be small enough to be proven correct.

The stated design goals of contemporary systems such as GCOS or OS/360 are to meet the first requirement (albeit unsuccessfully). The second requirement is generally not met by contemporary systems since they usually include "bypasses" to permit special software to operate or must suspend the reference monitor to provide addressability for the operating system in exercising its service functions. The best known of these is the bypass in OS/360 for the IBM supplied service aid, IMASPZAP (SUPERZAP). <IBM70> Finally and most important, current operating systems are so large, so complex, and so monolithic that one cannot begin to attempt a formal proof or certification of their correct implementation.

1.3.3 Hypothesis: Multics is "Secureable"

The computer security technology panel identified the general class of descriptor driven processors [1] as extremely useful to the implementation of a reference monitor. Multics, as the most sophisticated of the descriptor-driven systems currently available, was hypothesized to be a potentially secureable system; that is, the Multics design was sufficiently well-organized and oriented towards security that the concept of a reference monitor could be implemented for Multics without fundamental changes to the facilities seen by Multics users. In particular, the Multics ring mechanism could protect the monitor from malicious or inadvertent tampering, and the Multics segmentation could

[1] Descriptor driven processors use some form of address translation through hardware interpretation of descriptor words or registers. Such systems include the Burroughs 6700, the Digital Equipment Corp. PDP-11/45, the Data General Nova 840, the DEC KI-10, the HIS 6180, the IBM 370/158 and 168, and several others not listed here.

enforce monitor mediation on every reference to data. However, the question of certifiability had not as yet been addressed in Multics. Therefore the Multics vulnerability analysis described herein was undertaken to:

a. Examine Multics for potential vulnerabilities.

b. Identify whether a reference monitor was practical for Multics.

c. Identify potential interim enhancements to Multics to provide security in a benign (restricted access) environment.

d. Determine the scope and dimension of a certification effort.

1.4 Sites Used

The vulnerability analysis described herein was carried out on the HIS 645 Multics Systems installed at the Massachusetts Institute of Technology and at the Rome Air Development Center. As the HIS 6180, the new Multics processor, was not available at the time of this study. This report will describe results of analysis of the HIS 645 only. Since the completion of the analysis, work has started on an evaluation of the security controls of Multics on the HIS 6180. Preliminary results of the work on the HIS 6180 are very briefly summarized in this report, to provide an understanding of the value of the evaluation of the HIS 645 in the context of the new hardware environment.

SECTION II

MULTICS SECURITY CONTROLS

This section provides a brief overview of the basic Multics security controls to provide necessary background for the discussion of the vulnerability analysis. However, a rather thorough knowledge of the Multics implementation is assumed throughout the rest of this document. More complete background material may be found in Lipner <LIP74>, Saltzer <SAL73>, Organick <ORG72>, and the _Multics Programmers' Manual_ <MPM73>.

The basic security controls of Multics fall into three major areas: hardware controls, software controls, and procedural controls. This overview will touch briefly on each of these areas.

2.1 Hardware Security Controls

2.1.1 Segmentation Hardware

The most fundamental security controls in the HIS 645 Multics are found in the segmentation hardware. The basic instruction set of the 645 can directly address up to 256K (2) distinct segments (3) at any one time, each segment being up to 256K words long. (4) Segments are broken up into 1K word pages (5) which can be moved between primary and secondary storage by software, creating a very large virtual memory. However, we will not treat paging throughout most of this evaluation as it is transparent to security. Paging must be implemented

(2) 1K = 1024 units.

(3) Current software table sizes restrict a process to about 1000 segments. However, by increasing these table sizes, the full hardware potential may be used.

(4) The 645 software restricted segments to 64K words for efficiency reasons.

(5) The 645 hardware also supports 64 word pages which were not used. The 6180 supports only a single page size which can be varied by field modification from 64 words to 4096 words. Initially, a size of 1024 words is being used. The supervisors on both the 645 and 6180 use _unpaged_ segments of length 0 mod 64.

correctly in a secure system. However, bugs in page control are generally difficult to exploit in a penetration, because the user has little or no control over paging operations.

Segments are accessed by the 645 CPU through segment descriptor words (SDW's) that are stored in the descriptor segment (DSEG). (See Figure 1.) To access segment N, the 645 CPU uses a processor register, the descriptor segment base register (DBR), to find the DSEG. It then accesses the Nth SDW in the DSEG to obtain the address of the segment and the access rights currently in force on that segment for the current user.

Each SDW contains the absolute address of the page table for the segment and the access control information. (See Figure 2.) The last 6 bits of the SDW determine the access rights to the segment - read, execute, write, etc. (6) Using these access control bits, the supervisor can protect the descriptor segment from unauthorized modification by denying access in the SDW for the descriptor segment.

2.1.2 Master Mode

To protect against unauthorized modification of the DBR, the processor operates in one of two states - master mode and slave mode. In master mode any instruction may be executed and access control checks are inhibited. (7) In slave mode, certain instructions including those which modify the DBR are inhibited. Master mode procedure segments are controlled by the class field in the SDW. Slave mode procedures may transfer to master mode procedures only through word zero of the master mode procedure to prevent unrestricted invocation of privileged programs. It is then the responsibility of the master mode software to protect itself from malicious calls by placing suitable protective routines beginning at location zero.

(6) A more detailed description of the SDW format may be found in the 645 processor manual <AGB71>.

(7) The counterpart of master mode on the HIS 6180 called privileged mode does not inhibit access control checking.

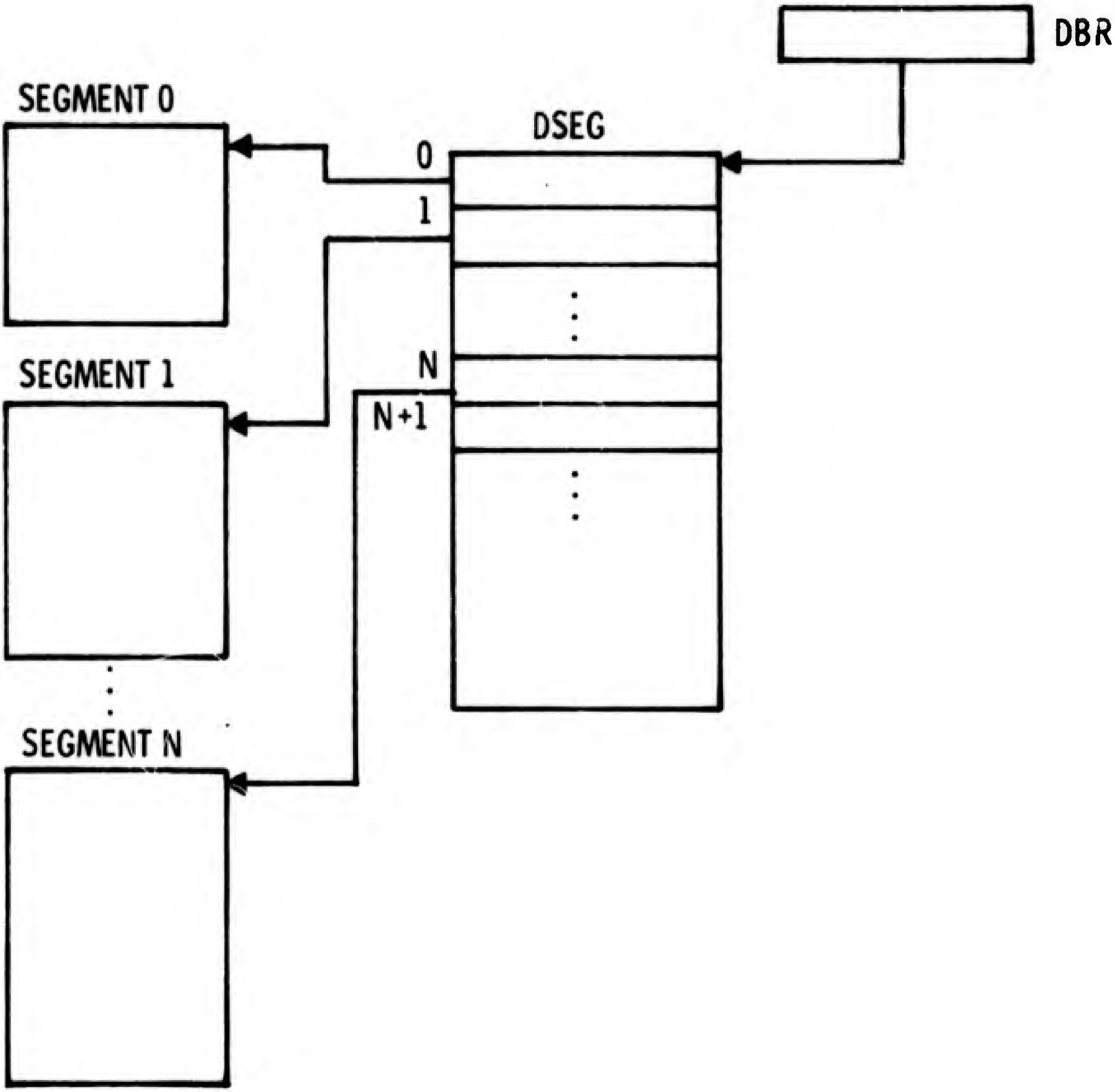


Figure 1.   Segmentation Hardware

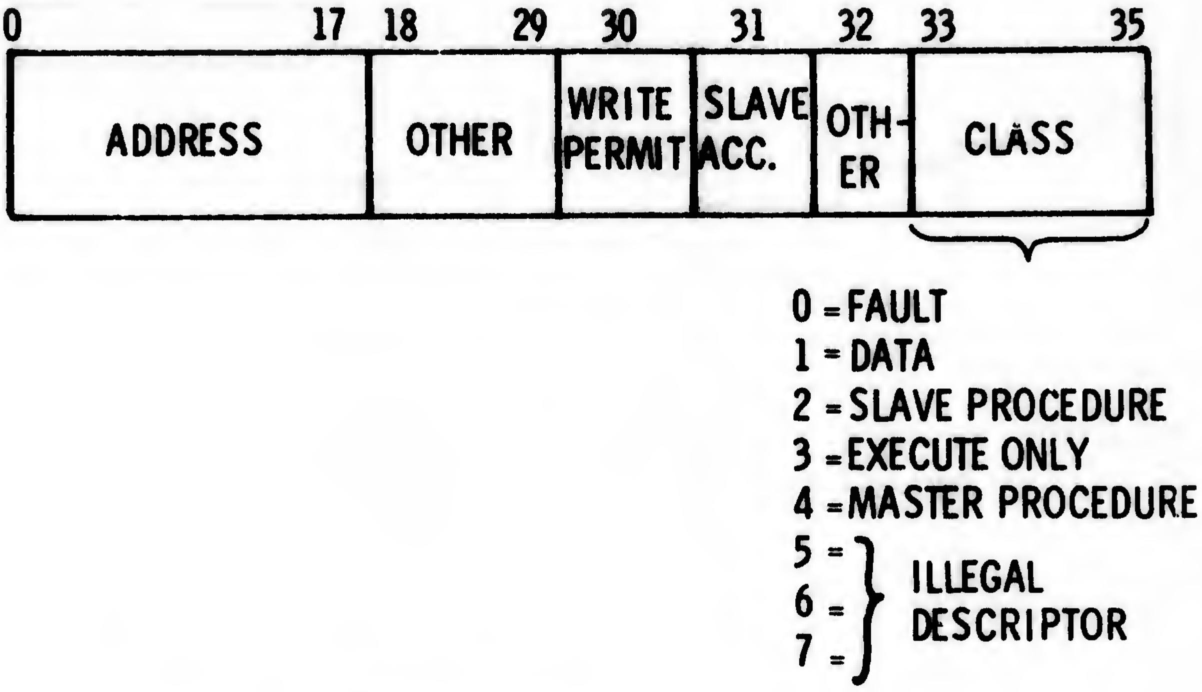


Figure 2. SDW Format

2.2 Software Security Controls

The most outstanding feature of the Multics security controls is that they operate on a basis of "form" rather than the classical basis of "content". That is to say, the Multics controls are based on operations on a uniform population of well defined objects, as opposed to the classical controls which rely on anticipating all possible types of accesses and make security essentially a battle of wits.

2.2.1 Protection Rings

The primary software security control on the 645 Multics system is the ring mechanism. It was originally postulated as desirable to extend the traditional master/slave mode relationship of conventional machines to permit layering within the supervisor and within user code (see Graham <GRA68>). Eight concentric rings of protection, numbered 0 - 7, are defined with higher numbered rings having less privilege than lower numbered rings, and with ring 0 containing the "hardcore" supervisor. (8) Unfortunately, the 645 CPU does not implement protection rings in hardware. (9) Therefore, the eight protection rings are implemented by providing eight descriptor segments for each process (user), one descriptor segment per ring. Special fault codes are placed in those SDW's which can be used for cross-ring transfers so that ring 0 software can intervene and accomplish the descriptor segment swap between the calling and called rings.

2.2.2 Access Control Lists

Segments in Multics are stored in a hierarchy of directories. A directory is a special type of segment that is not directly accessible to the user and provides a place to store names and other information about subordinate segments and directories. Each segment and directory has an access control list (ACL) in its parent directory entry controlling who may read (r), write (w), or execute (e) the segment or obtain status (s) of, modify (m) entries in, or append (a) entries to a directory. For example in Figure 3, the user Jones.Druid has read permission to segment ALPHA and has null access to segment BETA. However, Jones.Druid has modify permission to directory DELTA, so he can give himself access to segment BETA. Jones.Druid cannot give himself write access to segment ALPHA, because he does not have modify permission to directory GAMMA. In turn, the right to modify the access control lists of GAMMA and DELTA is controlled by the access control list of directory EPSILON, stored in the parent of EPSILON. Access control security checks for segments are enforced by the ring 0 software by setting the appropriate bits in the SDW at the time that a user attempts to add a segment to his address space.

(8) The original design called for 64 rings, but this was reduced to 8 in 1971.

(9) One of the primary enhancements of the HIS 6180 is the addition of ring hardware <SCHR72> and a consequent elimination of the need for master mode procedures in the user ring.

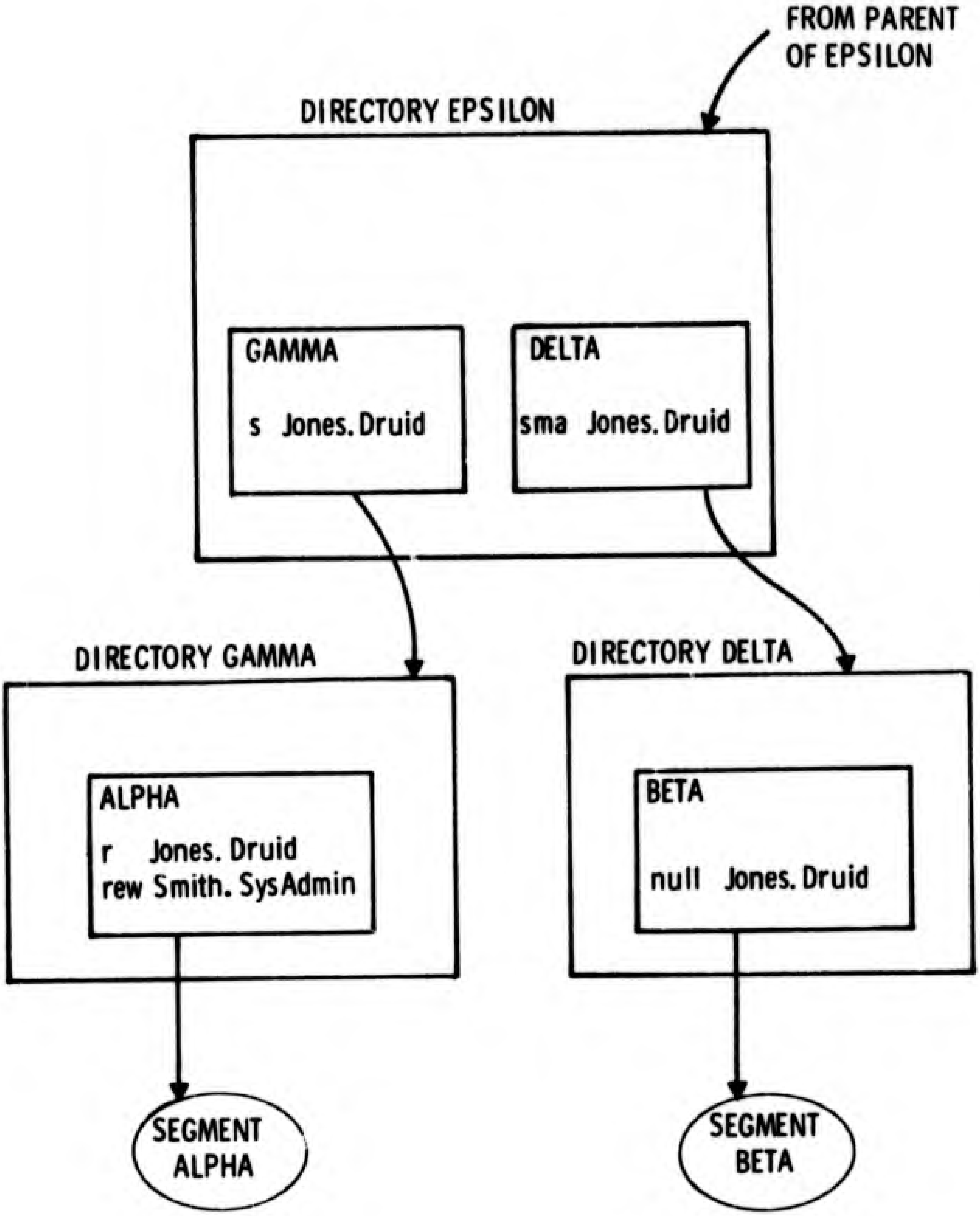


Figure 3. Directory Hierarchy

2.2.3 Protected Access Identification

In order to do access checking, the ring 0 software must have a protected, non-forgeable identification of a user to compare with the ACL entries. This ID is established when a user signs on to Multics and is stored in the process data segment (PDS) which is accessible only in ring 0 or in master mode, so that the user may not tamper with the data stored in the PDS.

2.2.4 Master Mode Conventions

By convention, to protect master mode software, the original design specified that master mode procedures were not to be used outside ring 0. If the master mode procedure ran in the user ring, the master mode procedure itself would be forced to play the endless game of wits of the classical supervisor call. The master mode procedure would have to include code to check for all possible combinations of input arguments, rather than relying on a fundamental set of argument independent security controls. As an aid (or perhaps hindrance) to playing the game of wits, each master mode procedure must have a master mode pseudo-operation code assembled into location 0. The master mode pseudo-operation generates code to test an index register for a value corresponding to an entry point in the segment. If the index register is invalid, the master mode pseudo-operation code saves the registers for debugging and brings the system down.

2.3 Procedural Security Controls

2.3.1 Enciphered Passwords

When a user logs in to Multics, he types a password as his primary authentication. Of course, the access control list of the password file denies access to regular users of the system. In addition, as a protection against loss of a system dump which could contain the password file, all passwords are stored in a "non-invertible" cipher form. When a user types his password, it is enciphered and compared with the stored enciphered version for validity. Clear text passwords are stored nowhere in the system.

2.3.2 Login Audit Trail

Each login and logout is carefully audited to check for attempts to guess valid user passwords. In addition, each user is informed of the date, time and terminal identification (if any) of last login to detect past compromises of the user's access rights. Further, the user is told the number of times his password has been given incorrectly since its last correct use.

2.3.3 Software Maintenance Procedures

The maintenance of the Multics software is carried out online on a dial-up Multics facility. A systems programmer prepares and nominally debugs his software for installation. He then submits his software to a library installer who copies and recompiles the source in a protected directory. The library installer then checks out the new software prior to installing it in the system source and object libraries. Ring 0 software is stored on a system tape that is reloaded into the system each time it is brought up. However, new system tapes are generated from online copies of the ring 0 software. The system libraries are protected against modification by the standard ACL mechanism. In addition, the library installers periodically check the date/time last modified of all segments in the library in an attempt to detect unauthorized modifications.

SECTION III

VULNERABILITY ANALYSIS

3.1 Approach Plan

It was hypothesized that although the fundamental design characteristics of Multics were sound, the implementation was carried out on an ad hoc basis and had security weaknesses in each of the three areas of security controls described in Section II - hardware, software, and procedures.

The analysis was to be carried out on a very limited basis with a less than one-half man month per month level of effort. Due to the manpower restrictions, a goal of one vulnerability per security control area was set. The procedure followed was to postulate a weakness in a general area, verify the weakness in the system, experiment with the weakness on the Rome Air Development Center (RADC) installation, and finally, using the resulting debugged penetration approach, exploit the weakness on the MIT installation.

An attempt was to be made to operate with the same type of ground rules under which a real agent would operate. That is, with each penetration, an attempt would be made to extract or modify sensitive system data without detection by the system maintenance or administrative personnel.

Several exploitations were successfully investigated. These included changing access fields in SDW's, changing protected identities in the PDS, inserting trap doors into the system libraries, and accessing the system password file.

3.2 Hardware Vulnerabilities

3.2.1 Random Failures

One area of significant concern in a system processing multi-level classified material is that of random hardware failures. As described in Section 2.1.1, the fundamental security of the system is dependent on the correct operation of the segmentation hardware. If this hardware is prone to error, potential security vulnerabilities become a significant problem.

To attempt a gross measure of the rate of security sensitive component failure, a procedure called the "subverter" was written to sample the security sensitive hardware on a frequent basis, testing for component failures which could compromise the security controls. The subverter was run in the background of an interactive process. Once each minute, the subverter received a timer interrupt and performed one test from the list described below. Assuming the test did not successfully violate security rules, the subverter would go to sleep for one minute before trying the next test. A listing of the subverter may be found in Appendix A.

The subverter was run for 1100 hours in a one year period on the MIT 645 system. The number of times each test was attempted is shown in Table 1. During the 1100 operating hours, no security sensitive hardware component failures were detected, indicating good reliability for the 645 security hardware. However, two interesting anomalies were discovered in the tests. First, one undocumented instruction (octal 471) was discovered on the 645. Experimentation indicated that the new instruction had no obvious impact on security, but merely seemed to store some internal register of no particular interest. The second anomaly was a design error resulting in an algorithmic failure of the hardware described in Section 3.2.2.

TABLE 1

Subverter Test Attempts

1100 Operating Hours

Test Name	# Attempts
1. Clear Associative Memory	3526
2. Store Control Unit	3466
3. Load Timer Register	3444
4. Load Descriptor Base Register	3422
5. Store Descriptor Base Register	3403
6. Connect I/O Channel	3378
7. Delay Until Interupt Signal	3359
8. Read Memory Controller Mask Register	3344
9. Set Memory Controller Mask Register	3328
10. Set Memory Controller Interrupt Cells	3309
11. Load Alarm Clock	3289
12. Load Associative Memory	3259
13. Store Associative Memory	3236
14. Restore Control Unit	3219
15. No Read Permission	3148
16. No Write Permission	3131
17. XED - No Read Permission	3113
18. XED - No Write Permission	3098
19. Tally Word Without Write Permission	3083
20. Bounds Fault <64K	2398
21. Bounds Fault >64K	2368
22. Illegal Opcodes	2108

Tests 1-14 are tests of master mode instructions. Tests 15 and 16 attempt simple violation of read and write permission as set on segment ACL's. Tests 17 and 18 are identical to 15 and 16 except that the faulting instructions are reached from an Execute Double instruction rather than normal instruction flow. Test 19 attempts to increment a tally word that is in a segment without write permission. Tests 20 and 21 take out of bounds faults on segments of zero length, forcing the supervisor to grow new page tables for them. Test 22 attempts execution of all the instructions marked illegal on the 645.

3.2.2 Execute Instruction Access Check Bypass

While experimenting with the hardware subverter, a sequence of code (10) was observed which would cause the hardware of the 645 to bypass access checking. Specifically, the execute instruction in certain cases described below would permit the executed instruction to access a segment for reading or writing without the corresponding permissions in the SDW.

This vulnerability occurred when the execute instruction was in certain restricted locations of a segment with at least read-execute (re) permission. (See Figure 4.) The execute instruction then referenced an object instruction in word zero of a second segment with at least R permission. The object instruction indirected through an ITS pointer in the first segment to access a word for reading or writing in a third segment. The third segment was required to be "active"; that is, to have an SDW pointing to a valid page table for the segment. If all these conditions were met <u>precisely</u>, the access control fields in the SDW of the third segment would be ignored and the object instruction permitted to complete without access checks.

The exact layout of instructions and indirect words was crucial. For example, if the object instruction used a base register rather than indirecting through the segment containing the execute instruction (i.e., staq ap|0 rather than staq 6,*), then the access checks were done properly. Unfortunately, a complete schematic of the 645 was not available to determine the exact cause of the bypass. In informal communications with Honeywell, it was indicated that the error was introduced in a field modification to the 645 at MIT and was then made to all processors at all other sites.

This hardware bug represents a violation of one of the most fundamental rules of the Multics design - the checking of <u>every</u> reference to a segment by the hardware. This bug was not caused by fundamental design problems. Rather, it was caused by carelessness by the hardware engineering personnel.

[10] The subverter was designed to test sequences of code in which single failures could lead to security problems. Some of these sequences exercised relatively complex and infrequently used instruction modifications which experience had shown were prone to error.

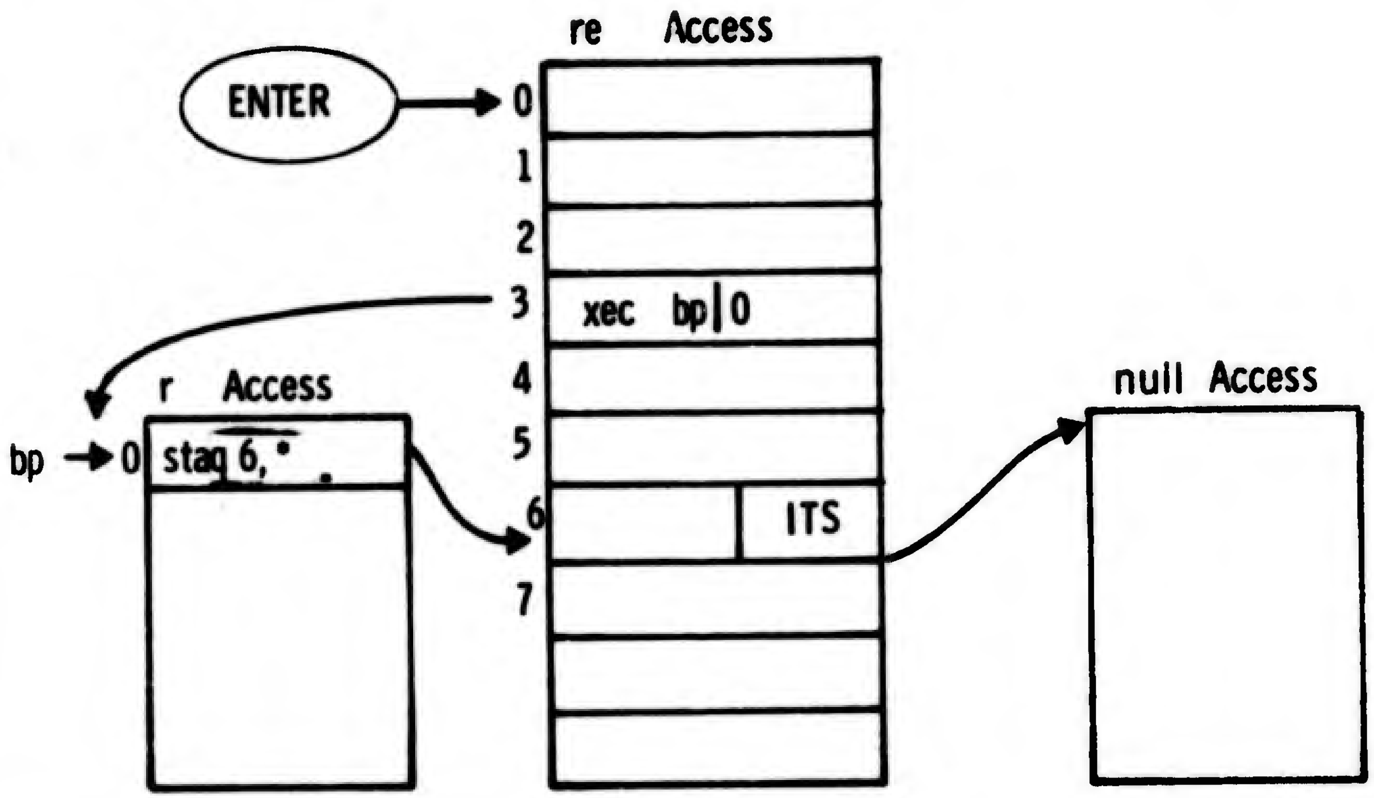


Figure 4. Execute Instruction Bypass

No attempt was made to make a complete search for additional hardware design bugs, as this would have required logic diagrams for the 645. It was sufficient for this effort to demonstrate one vulnerability in this area.

3.2.3 Preview of 6180 Hardware Vulnerabilities

While no detailed look has been taken at the issue of hardware vulnerabilities on the 6180, the very first login of an ESD analyst to the 6180 inadvertently discovered a hardware vulnerability that crashed the system. The vulnerability was found in the Tally Word Without Write Permission test of the subverter. In this test, when the 6180 processor encountered the tally word without write permission, it signalled a "trouble" fault rather than an "access violation" fault. The "trouble" fault is normally signalled only when a fault occurs during the signalling of a fault. Upon encountering a "trouble" fault, the software normally brings the system down.

It should be noted that the HIS 6180 contains very new and complex hardware that, as of this publication, has not been completely "shaken down". Thus, Honeywell still quite reasonably expects to find hardware problems. However, the inadequacy of "testing" for security vulnerabilities applies equally well to hardware as to software. Simply "shaking down" the hardware cannot find all the possible vulnerabilities.

3.3 Software Vulnerabilities

Although the approach plan for the vulnerability analysis only called for locating one example of each class of vulnerability, three software vulnerabilities were identified as shown below. Again, the search was neither exhaustive nor systematic.

3.3.1 Insufficient Argument Validation

Because the 645 Multics system must simulate protection rings in software, there is no direct hardware validation of arguments passed in a subroutine call from a less privileged ring to a more privileged ring. Some form of validation is required, because a malicious user could call a ring 0 routine that stores information through a user supplied pointer. If the malicious user supplied a pointer to data to which ring 0 had write permission but to which the user ring did not, ring 0 could be "tricked" into causing a security violation.

To provide validation, the 645 software ring crossing mechanism requires all gate segments (11) to declare to the "gatekeeper" the following information:

1. number of arguments expected
2. data type of each arguments
3. access requirements for each argument- read only or read/write.

This information is stored by convention in specified locations within the gate segment. (12) The "gatekeeper" invokes an argument validation routine that inspects the argument list being passed to the gate to ensure that the declared requirements are met. If any test fails, the argument validator aborts the call and signals the condition "gate_error" in the calling ring.

In February 1973, a vulnerability was identified in the argument validator that would permit the "fooling" of ring 0 programs. The argument validator's algorithm to validate read or read/write permission was as follows: First copy the argument list into ring 0 to prevent modification of the argument list by a process running on another CPU in the system while the first process is in ring 0 and has completed argument validation. Next, force indirection through each argument pointer to obtain the segment number of the target argument. Then look up the segment in the calling ring's descriptor segment to check for read or write permission.

The vulnerability is as follows: (See figure 5.) An argument pointer supplied by the user is constructed to contain an IDC modifier (increment address, decrement tally, and continue) that causes the first reference through the indirect chain to address a valid argument. This first reference is the one made by the

(11) A gate segment is a segment used to cross rings. It is identified by R2 and R3 of its ring brackets R1, R2, R3 being different. See Organick <ORG72> for a detailed description of ring brackets.

(12) For the convenience of authors of gates, a special "gate language" and "gate compiler" are provided to generate properly formatted gates. Using this language, the author of the gate can declare the data type and access requirement of each argument.

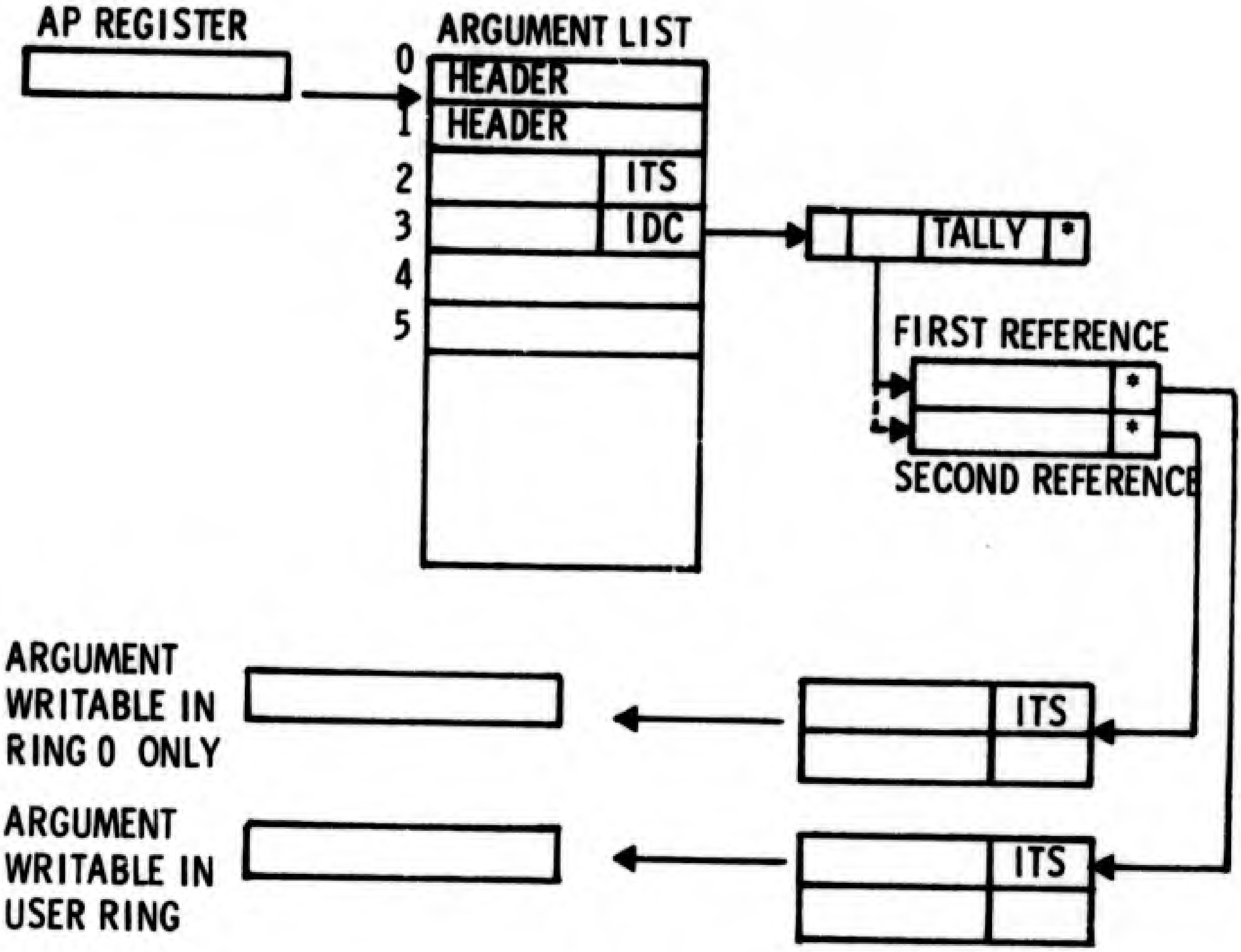


Figure 5. Insufficient Argument Validation

argument validator. The reference through the IDC modifier increments the address field of the tally word causing it to point to a different indirect word which in turn points to a different ITS pointer which points to an argument which is writable in ring 0 only. The second reference through this modified indirect chain is made by the ring 0 program which proceeds to write data where it shouldn't. (13)

This vulnerability resulted from violation of a basic rule of the Multics design - that all arguments to a more privileged ring be validated. The problem was not in the fundamental design - the concept of a software argument validator is sound given the lack of ring hardware. The problem was an ad hoc implementation of that argument validator which overlooked a class of argument pointers.

Independently, a change was made to the MIT system which fixed this vulnerability in February 1973. The presence and exploitability of the vulnerability were verified on the RADC Multics which had not been updated to the version running at MIT. The method of correction chosen by MIT was rather "brute force." The argument validator was changed to require the modifier in the second word of each argument pointer always to be zero. This requirement solves the specific problem of the IDC modifier, but not the general problem of argument validation.

3.3.2 Master Mode Transfer

As described in Sections 2.1.2 and 2.2.4, the 645 CPU has a master mode in which privileged instructions may be executed and in which access checking is inhibited although address translation through segment and page tables is retained. (14) The original design of the Multics protection rings called for master mode code to be

(13) Depending on the actual number of references made, the malicious user need only vary the number of indirect words pointing to legal and illegal arguments. We have assumed for simplicity here that the validator and the ring 0 program make only one reference each.

(14) The 645 also has an absolute mode in which all addresses are absolute core addresses rather than being translated by the segmentation hardware. This mode is used only to initialize the system.

restricted to ring 0 by convention. (15) This convention caused the fault handling mechanism to be excessively expensive due to the necessity of switching from the user ring into ring 0 and out again using the full software ring crossing mechanism. It was therefore proposed and implemented that the _signaller_, the module responsible for processing faults to be signalled to the user, (16) be permitted to run in the user ring to speed up fault processing. The signaller is a master mode procedure, because it must execute the RCU (_R_estore _C_ontrol _U_nit) instruction to restart a process after a fault.

The decision to move the signaller to the user ring was not felt to be a security problem by the system designers, because master mode procedures could only be entered at word zero. The signaller would be assembled with the master mode pseudo-operation code at word zero to protect it from any malicious attempt by a user to execute an arbitrary sequence of instructions within the procedure. It was also proposed, although never implemented, that the code of master mode procedures in the user ring be specially audited. However as we shall see in Section 3.4.4, auditing does not guarantee victory in the "battle of wits" between the implementor and the penetrator. Auditing cannot be used to make up for fundamental security weaknesses.

It was postulated in the ESD/MCI vulnerability analysis that master mode procedures in the user ring represent a fundamental violation of the Multics security concept. Violating this concept moves the security controls from the basic hardware/software mechanism to the cleverness of the systems programmer who, being human, makes mistakes and commits oversights. The master mode procedures become classical "supervisor calls" with no rules for "sufficient" security checks. In fact, upon close examination of the signaller, this hypothesis was found to be true.

(15) This convention is enforced on the 6180. Privileged mode (the 6180 analogy to the 645 master mode) only has effect in ring 0. Outside ring 0, the hardware ignores the privileged mode bit.

(16) The signaller processed such faults as "zerodivide" and access violation which are signalled to the user. Page faults and segment faults which the user never sees are processed elsewhere in ring 0.

The master mode pseudo-operation code was designed only to protect master mode procedures from random calls within ring 0. It was not designed to withstand the attack of a malicious user, but only to operate in the relatively benign environment of ring 0.

The master mode program shown in Figure 6 assembles into the interpreted object code shown in Figure 7. The master mode procedure can only be entered at location zero. (17) By convention, the n entry points to the procedure are numbered from 0 to n-1. The number of the desired entry point must be in index register zero at the time of the call. The first two instructions in the master mode sequence check to ensure that index register zero is in bounds. If it is, the transfer on no carry (tnc) instruction indirects through the transfer vector to the proper entry. If index register zero is out of bounds, the processor registers are saved for debugging and control is transferred to "mxerror," a routine to crash the system because of an unrecoverable error.

This transfer to mxerror is the most obvious vulnerability. By moving the signaller into the user ring, the designers allowed a user to arbitrarily crash the system by transferring to signaller|0 with a bad value in index register zero. This vulnerability is not too serious, since it does not compromise information and could be repaired by changing mxerror to handle the error, rather than crashing the system.

However, there is a much more subtle and dangerous vulnerability here. The tra lp|12,* instruction that is used to call mxerror believes that the lp register points to the linkage section of the signaller, which it should if the call were legitimate. However, a malicious user may set the lp register to point wherever he wishes, *permitting him to transfer to an arbitrary location while the CPU is still in master mode*. The key is the transfer in master mode, because this permits a transfer to an arbitrary location within another master mode procedure without access checking and without the restriction of entering at word zero. Thus, the penetrator need only find a convenient store instruction to be able to write into his own descriptor segment, for example. Figure 8 shows the use of a sta bp|0 instruction to change the contents of an SDW illegally.

---

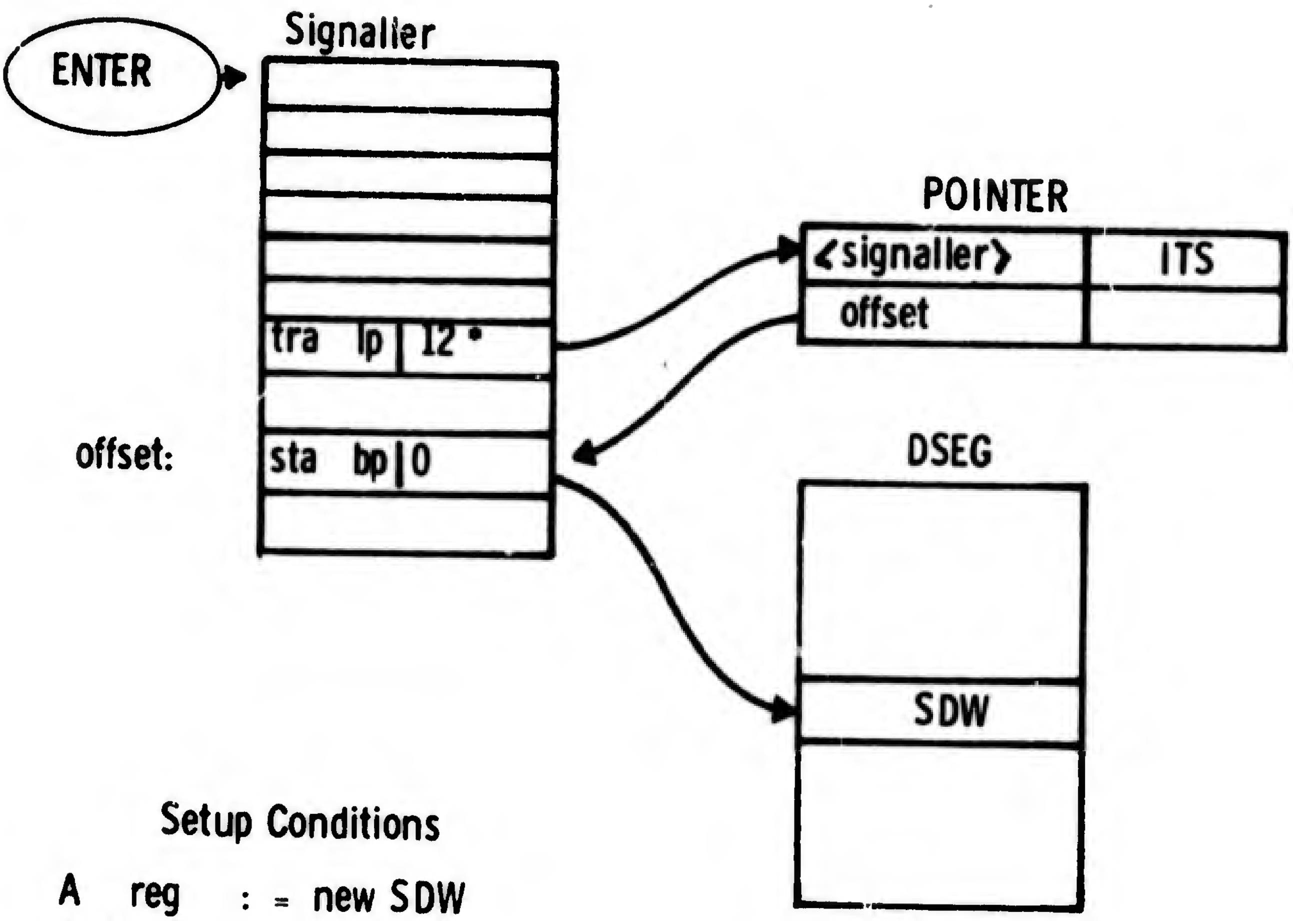
(17) This restriction is enforced by hardware described in Section 2.1.2.

```
            name        master_test
            mastermode
            entry       a
            entry       b
a:          code
            ...
b:          code
            ...
            end
```

Figure 6.   Master Mode Source Code

```
            cmpx0       2,du        "call in bounds?
            tnc         transfer_vector,0   "Yes, go to  entry
            stb         sp|0        "Illegal call here
            sreg        sp|10       "save registers
            eapap       arglist     "set up call
            stcd        sp|24
            tra         lp|12,*     "lp|12 points to mxerror
a:          code
            ...
b:          code
            ...
transfer_vector:
            tra         a
            tra         b
            end
```

Figure 7.   Master Mode Interpreted Object Code



Setup Conditions

A reg	:=	new SDW
Index 0	:=	-1
lp	:=	address (POINTER) - 12
POINTER	:=	address (sta instruction)
bp	:=	address (SDW)

Figure 8. Store with Master Mode Transfer

There is one major difficulty in exploiting this vulnerability. The instruction to which control is transferred must be chosen with extreme care. The instructions immediately following the store must provide some orderly means of returning control to the malicious user without doing uncontrolled damage to the system. If a crucial data base is garbled, the system will crash leaving a core dump which could incriminate the penetrator.

This vulnerability was identified by ESD/MCI in June 1972. An attempt to use the vulnerability led to a system crash for the following reason: Due to an obsolete listing of the signaller, the transfer was made to an LDBR (Load Descriptor Base Register) instruction instead of the expected store instruction. The DBR was loaded with a garbled value, and the system promptly crashed. The system maintenance personnel, being unaware of the presence of an active penetration, attributed the crash to a disk read error.

The Master Mode Transfer vulnerability resulted from a violation of the fundamental rule that master mode code shall not be executed outside ring 0. The violation was not made maliciously by the system implementors. Rather it occurs because of the interaction of two seemingly independent events: the ability to transfer via the ip without the system being able to check the validity of the ip setting, and the ability for that transfer to be to master mode code. The separation of these events made the recognition of the problem unlikely during implementation.

3.3.3 Unlocked Stack Base

The 645 CPU has eight 18-bit registers that are used for inter-segment references. Control bits are associated with each register to allow it to be paired with another register as a word number-segment number pair. In addition, each register has a lock bit, settable only in master mode, which protects its contents from modification. By convention, the eight registers are named and paired as shown in Table 2.

TABLE 2

Base Register Pairing

Number	Name	Use	Pairing
0	ap	argument pointer	paired with ab
1	ab	argument base	unpaired
2	bp	unassigned	paired with bb
3	bb	unassigned	unpaired
4	lp	linkage pointer	paired with lb
5	lb	linkage base	unpaired
6	sp	stack pointer	paired with sb
7	sb	stack base	unpaired

During the early design of the Multics operating system, it was felt that the ring 0 code could be simplified if the stack base (sb) register were locked, that is, could only be modified in master mode. The sb contained the segment number of the user stack which was guaranteed to be writeable. If the sb were locked, then the ring 0 fault and interrupt handlers could have convenient areas in which to store stack frames. After Multics had been released to users at MIT, it was realized that locking the stack base unnecessarily constrained language designers. Some languages would be extremely difficult to implement without the capability of quickly and easily switching between stack segments. Therefore, the system was modified to no longer lock the stack base.

When the stack base was unlocked, it was realized that there was code scattered throughout ring 0 which assumed that the sb always pointed to the stack. Therefore, ring 0 was "audited" for all code which depended on the locked stack base. However, the audit was never completed and the few dependencies identified were in general not repaired until much later.

As part of the vulnerability analysis, it was hypothesized that such an audit for unlocked stack base problems was presumably incomplete. The ring 0 code is so large that a subtle dependency on the sb register could easily slip by an auditor's notice. This, in fact proved to be true as shown below:

Section 3.3.2 showed that the master mode pseudo-operation code believed the value in the ip register and transferred through it. Figure 7 shows that the master mode pseudo-operation code also depends on the sb pointing to a writeable stack segment. When an illegal master mode call is made, the registers are saved on the stack prior to calling "mxerror" to crash the system. This code was designed prior to the unlocking of the stack base and was not detected in the system audit. The malicious user need only set the sp-sb pair to point anywhere to perform an illegal store of the registers with master mode privileges.

The exploitation of the unlocked stack base vulnerability was a two step procedure. The master mode pseudo-operation code stored all the processor registers in an area over 20 words long. This area was far too large for use in a system penetration in which at most one or two words are modified to give the agent the privileges he requires. However, storing a large number of words could be very useful to install a "trap door" in the system -- that is a sequence of code which when properly invoked provides the penetrator with the needed tools to subvert the system. Such a "trap door" must be well hidden to avoid accidental discovery by the system maintenance personnel.

It was noted that the linkage segments of several of the ring 0 master mode procedures were preserved as separate segments rather than being combined in a single linkage segment. Further, these linkage segments were themselves master mode procedures. Thus, segments such as signaller, fim, and emergency_shutdown had corresponding master mode linkage segments signaller.link, fim.link, and emergency_shutdown.link. Linkage segments contain a great deal of information used only by the binder and therefore contain a great deal of extraneous information in ring 0. For this reason, a master mode linkage segment is an ideal place to conceal a "trap door." There is a master mode procedure called emergency_shutdown that is used to place the system in a consistent state in the event of a crash. Since emergency_shutdown is used only at the time of a system crash, its linkage segment, emergency_shutdown.link, was chosen to be used for the "trap door".

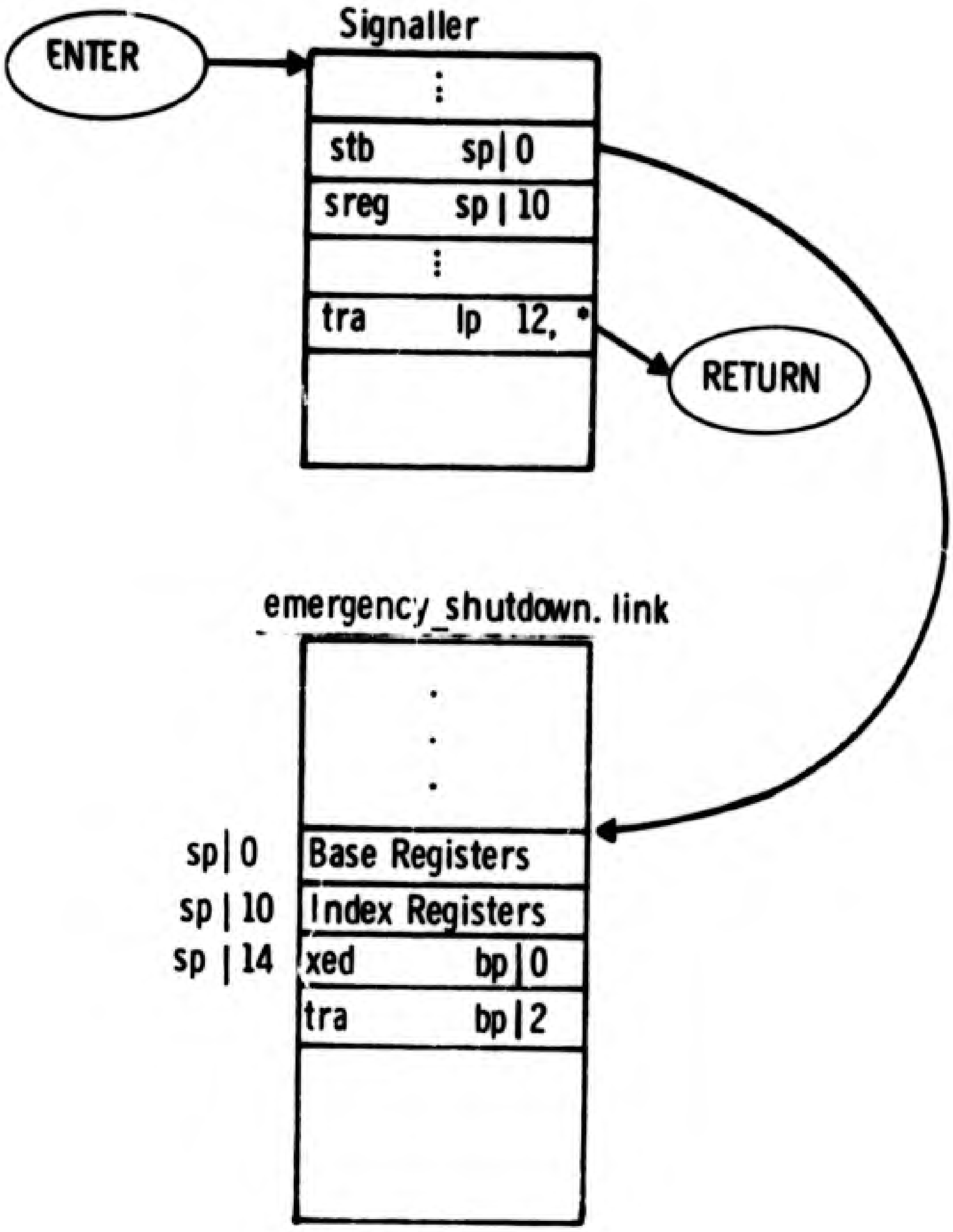
The first step of the exploitation of the unlocked stack base is shown in Figure 9. (18) The signaller is entered at location 0 with an invalid index register 0. The stack pointer is set to point to an area of extraneous storage in emergency_shutdown.link. The AQ register contains a two instruction "trap door" which when executed in master mode can load or store any 36-bit word in the system. The index registers could be used to hold a longer "trap door"; however, in this case the xed bp|0, tra bp|2 sequence is sufficient. The base registers, index registers, and AQ register are stored into emergency_shutdown.link, thus laying the "trap door". Finally a transfer is made indirect through lp|12 which has been pre-set as a return pointer. (19)

Step two of the exploitation of the unlocked stack base is shown in Figure 10. The calling program sets the bp register to point to the desired instruction pair and transfers to word zero of the signaller with an invalid value in index register 0. The signaller saves its registers on the user's stack frame since the sp has not been changed. It then transfers indirect through lp|12 which has been set to point to the "trap door" in emergency_shutdown.link. The first instruction of the "trap door" is an execute double (XED) which permits the user (penetration agent) to specify any two arbitrary instructions to be executed in master mode. In this example, the instruction pair loads the Q register from a word in the stack frame (20) and then stores indirect through a pointer in the stack to an SDW in the descriptor segment. The second instruction in the "trap door" transfers back to the calling program, and the penetrator may go about his business.

(18) Listings of the code used to exploit this vulnerability are found in Appendix B.

(19) This transfer uses the Master Mode Transfer vulnerability to return. This is done primarily for convenience. The fundamental vulnerability is the storing through the sp register. Without the Master Mode Transfer, exploitation of the Unlocked Stack Base would have been more difficult, although far from impossible.

(20) It should be noted that only step one changed the value of the sp. In step two, it is very useful to leave the sp pointing to a valid stack frame.



Setup Conditions

AQ register := xed bp|0; tra bp|2
Index 0 := -1
sp := address (unused storage in emergency_shutdown.link)
lp|12 := address (return location)

Figure 9. Unlocked Stack Base (Step 1)

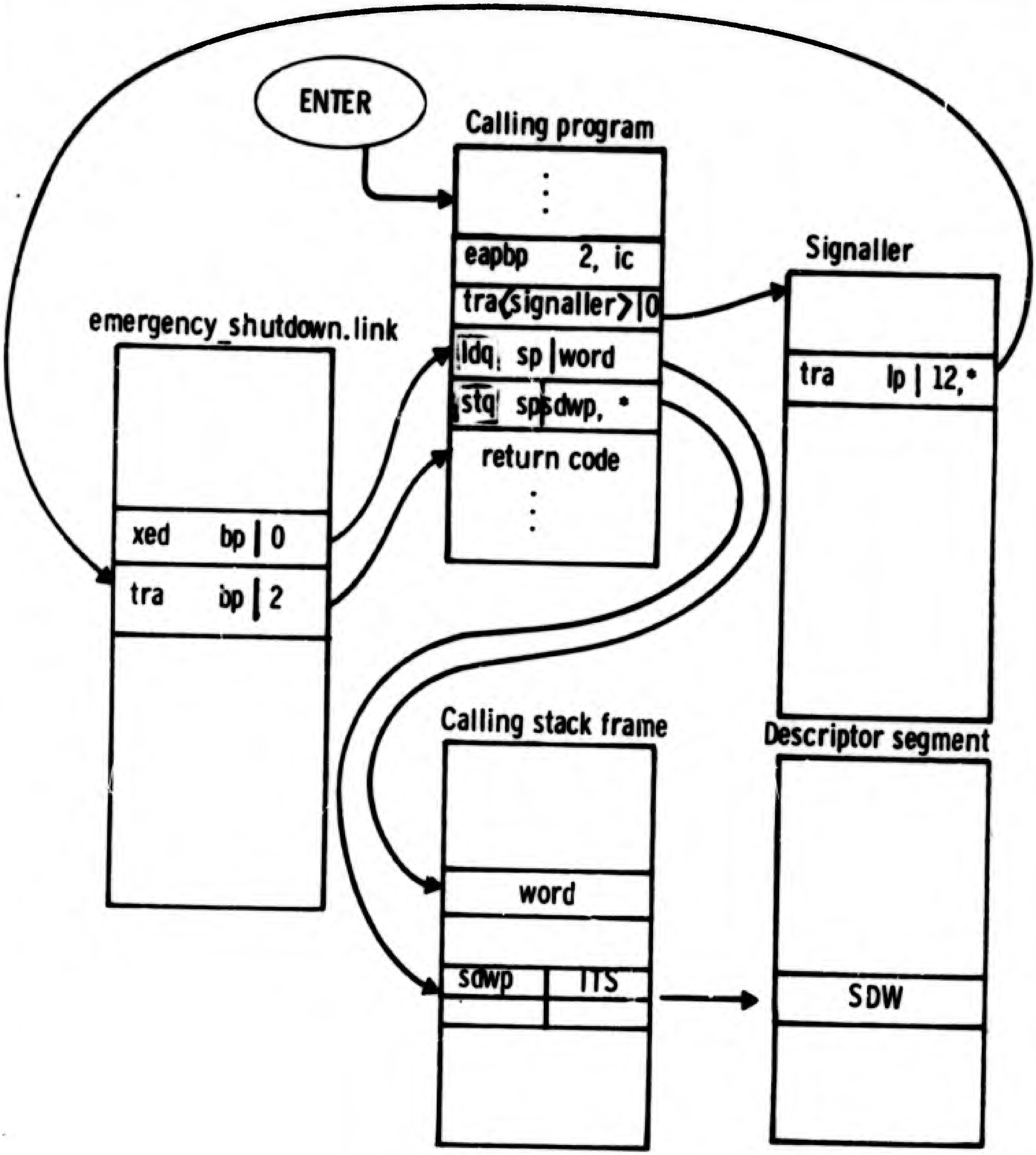


Figure 10. Unlocked Stack Base (Step 2)

The "trap door" inserted in emergency_shutdown.link remained in the system until the system was reinitialized. (21) At initialization time, a fresh copy of all ring zero segments is read in from the system tape erasing the "trap door". Since system initializations occur at least once per day, the penetrator must execute step one before each of his working sessions. Step two is then executed each time he wishes to access or modify some word in the system.

The unlocked stack base vulnerability was identified in June 1972 with the Master Mode Transfer Vulnerability. It was developed and used at the RADC site in September 1972 without a single system crash. In October 1972, the code was transferred to the MIT site. Due to lack of good telecommunications between the two sites, the code was manually retyped into the MIT system. A typing mistake was made that caused the word to be stored into the SDW to always be zero (See Figure 10). When an attempt was made to set slave access-data in the SDW of the descriptor segment itself, (22) the SDW of the descriptor segment was set to zero causing the system to crash at the next LDBR instruction or segment initiation. The bug was recognized and corrected immediately, but later in the day, a second crash occurred when the SDW for the ring zero segment fim (the fault intercept module) was patched to slave access-write permit-data rather than slave access-write permit-slave procedure. In more straightforward terms, the SDW was set to read-write rather than read-write-execute. Therefore, when the system next attempted to execute the fim it took a no-execute permission fault and tried to execute the fim, thus entering an infinite loop crashing the system.

3.3.4 Preview of 6180 Software Vulnerabilities

The 6180 hardware implementation of rings renders invalid the attacks described here on the 645. This is not to say, however, that the 6180 Multics is free of vulnerabilities. A cursory examination of the 6180 software has revealed the existence of several software vulnerabilities, any one of which can be used to access

[21] See Section 3.4.5 for more lasting "trap doors".

[22] The attempt here was to dump the contents of the descriptor segment on the terminal. The user does not normally have read permission to his own descriptor segment.

any information in the system. These vulnerabilities were identified with comparable levels of effort to those shown in Section 3.5.

3.3.4.1 No Call Limiter Vulnerability

The first vulnerability is the No Call Limiter vulnerability. This vulnerability was caused by the call limiter not being set on gate segments, allowing the user to transfer to any instruction within the gate rather than to just an entry transfer vector. This vulnerability gives the penetrator the same capabilities as the Master Mode Transfer vulnerability.

3.3.4.2 SLT-KST Dual SDW Vulnerability

The second vulnerability is the SLT-KST Dual SDW vulnerability. When a user process was created on the 645, separate descriptor segments were created for each ring, with the ring 0 SDW's being copied from the segment loading table (SLT). The ring 0 descriptor segment was essentially a copy of the SLT for ring 0 segments. The ring 4 descriptor segment zeroed out most SDW's for ring 0 segments. Non-ring 0 SDW's were added to both the ring 0 and ring 4 descriptor segments from the Known Segment Table (KST) during segment initiation. Upon conversion to the 6180, the separate descriptor segments for each ring were merged into one descriptor segment containing ring brackets in each SDW <IPC73>. The ring 0 SDW's were still taken from the SLT and the non-ring 0 SDW's from the KST as on the 645.

The system contains several gates from ring 4 into ring 0 of varying levels of privilege. The least privileged gate is called hcs_ and may be used by all users in ring 4. The most privileged gate is called hphcs_ and may only be called by system administration personnel. The gate hphcs_ contains routines to shut the system down, access any segment in the system, and patch ring 0 data bases. If a user attempts to call hphcs_ in the normal fashion, hphcs_ is entered into the KST, an SDW is assigned, and access rights are determined from the access control list stored in hphcs_'s parent directory. Since most users would not be on the access control list of hphcs_, access would be denied. Ring 0 gates, however, also have a second segment number assigned from the segment loading table (SLT). This duplication posed no problem on the 645, since SLT SDW's were valid only in the ring 0 descriptor segment. However on the 6180, the KST SDW for hphcs_ would be null access ring brackets 0,0,5, but the SLT SDW would read-execute (re) access, ring brackets 0,0,5. Therefore, the penetrator need only transfer to the appropriate absolute segment number rather than using dynamic linking to gain access to any hphcs_ capability. This vulnerability was considerably easier to use than any of the others and was carried through identification, confirmation, and exploitation in less than 5 man-hours total (See Section 3.5).

3.3.4.3 Additional Vulnerabilities

The above mentioned 6180 vulnerabilities have been identified and repaired by Honeywell. The capabilities of the SLT-KST Dual SDW vulnerability were demonstrated to Honeywell on 14 September 1973 in the form of an illegal message to the operator's console at the 6180 site in the Honeywell plant in Phoenix, Arizona. Honeywell did not identify the cause of the vulnerability until March 1974 and installed a fix in Multics System 23.6. As of the time of this publication, additional vulnerabilities have been identified but at this time have not been developed into a demonstration.

3.4 Procedural Vulnerabilities

This section describes the exploitation by a remote user of several classes of procedural vulnerabilities. No attempt was made to penetrate physical security, as there were many admitted vulnerabilities in this area. In particular, the machine room was not secure and communications lines were not encrypted. Rather, this section looks at the areas of auditing, system configuration control, (23) passwords, and "privileged" users.

3.4.1 Dump and Patch Utilities

To provide support to the system maintenance personnel, the Multics system includes commands to dump or patch any word in the entire virtual memory. These

(23) System configuration control is a term derived from Air Force procurement procedures and refers to the control and management of the hardware and software being used in a system with particular attention to the software update tasks. It is not to be confused with the Multics dynamic reconfiguration capability which permits the system to add and delete processors and memories while the system is running.

utilities are used to make online repairs while the system continues to run. Clearly these commands are very dangerous, since they can bypass all security controls to access otherwise protected information, and if misused, can cause the system to crash by garbling critical data bases. To protect the system, these commands are implemented by special privileged gates into ring zero. The access control lists on these gates restrict their use to system maintenance personnel by name as authenticated by the login procedure. Thus an ordinary user nominally cannot access these utilities. To further protect the system, the patch utility records on the system operator's console every patch that is made. Thus, if an unexpected or unauthorized patch is made, the system operator can take immediate action by shutting the system down if necessary.

Clearly dump and patch utilities would be of great use to a system penetrator, since they can be used to facilitate his job. Procedural controls on the system dump and patch routines prevent the penetrator from using them by the ACL restrictions and the audit trail. However by using the software vulnerabilities described in section 3.3, these procedural controls may be bypassed and the penetration agent can implement his own dump and patch utilities as described below.

Dump and patch utilities were implemented on Multics using the Unlocked Stack Base and Insufficient Argument Validation vulnerabilities. These two vulnerabilities demonstrated two basically different strategies for accessing protected segments. These two strategies developed from the fact that the Unlocked Stack Base vulnerability operates in ring 4 master mode, while the Insufficient Argument Validation vulnerability operates in ring 0 slave mode. In addition, there was a requirement that a minimal amount of time be spent with the processor in an anomalous state - ring 4 master mode or ring 0 illegal code. When the processor is in an anomalous state, unexpected interrupts or events could cause the penetrator to be exposed in a system crash.

3.4.1.1 Use of Insufficient Argument Validation

As was mentioned above, the HIS 645 implementation of Multics simulates protection rings by providing one descriptor segment for each ring. Patch and dump utilities can be implemented using the Insufficient Argument Validation vulnerability by realizing that the ring zero descriptor segment will have entries for segments which are not accessible from ring 4. Conceptually, one could copy an SDW for some segment from the ring 0 descriptor segment to the ring 4 descriptor segment and be guaranteed at least as much access as available in ring 0. Since the segment number of a segment is the same in all rings, this approach is very easy to implement.

The exact algorithm is shown in flow chart form in Figure 11. In block 2 of the flow chart, the ring 4 SDW is read from the ring 4 descriptor segment (wdseg) using the Insufficient Argument Validation vulnerability. Next the ring 0 SDW is read from the ring 0 descriptor segment (dseg). The ring 0 SDW must now be checked for validity, since the segment may not be accessible even in ring 0. (24) An invalid SDW is represented by all 36 bits being zero. One danger present here is that if the segment in question is deactivated, (25) the SDW being checked may be invalidated while it is being manipulated. This event could conceivably have disastrous results, but as we shall see in Section 3.4.2, the patch routine need only be used on segments which are never deactivated. The dump routine can do no harm if it accidentally uses an invalid SDW, as it always only *reads* using the SDW, conceivably reading garbage but nothing else. Further, deactivation of the segment is highly unlikely since the segment is in "use" by the dump/patch routine.

If the ring 0 SDW is invalid, an error code is returned in block 5 of the flow chart and the routine terminates. Otherwise, the ring 0 SDW is stored into the ring 4 descriptor segment (wdseg) with read-execute-write access by turning on the SDW bits for slave access, write permission, slave procedure. (See Figure 2). Now the dump or patch can be performed without using the vulnerability to load or store each 36 bit word

(24) As an additional precaution, ring 0 slave mode programs run under the same access rules as all other programs. A valid SDW entry is made for a segment in any ring only if the user is on the ACL for the segment. We shall see in Section 3.4.2 how to get around this "security feature".

(25) A segment is deactivated when its page table is removed from core. Segment deactivation is performed on a least recently used basis, since not all page tables may be kept in core at one time.

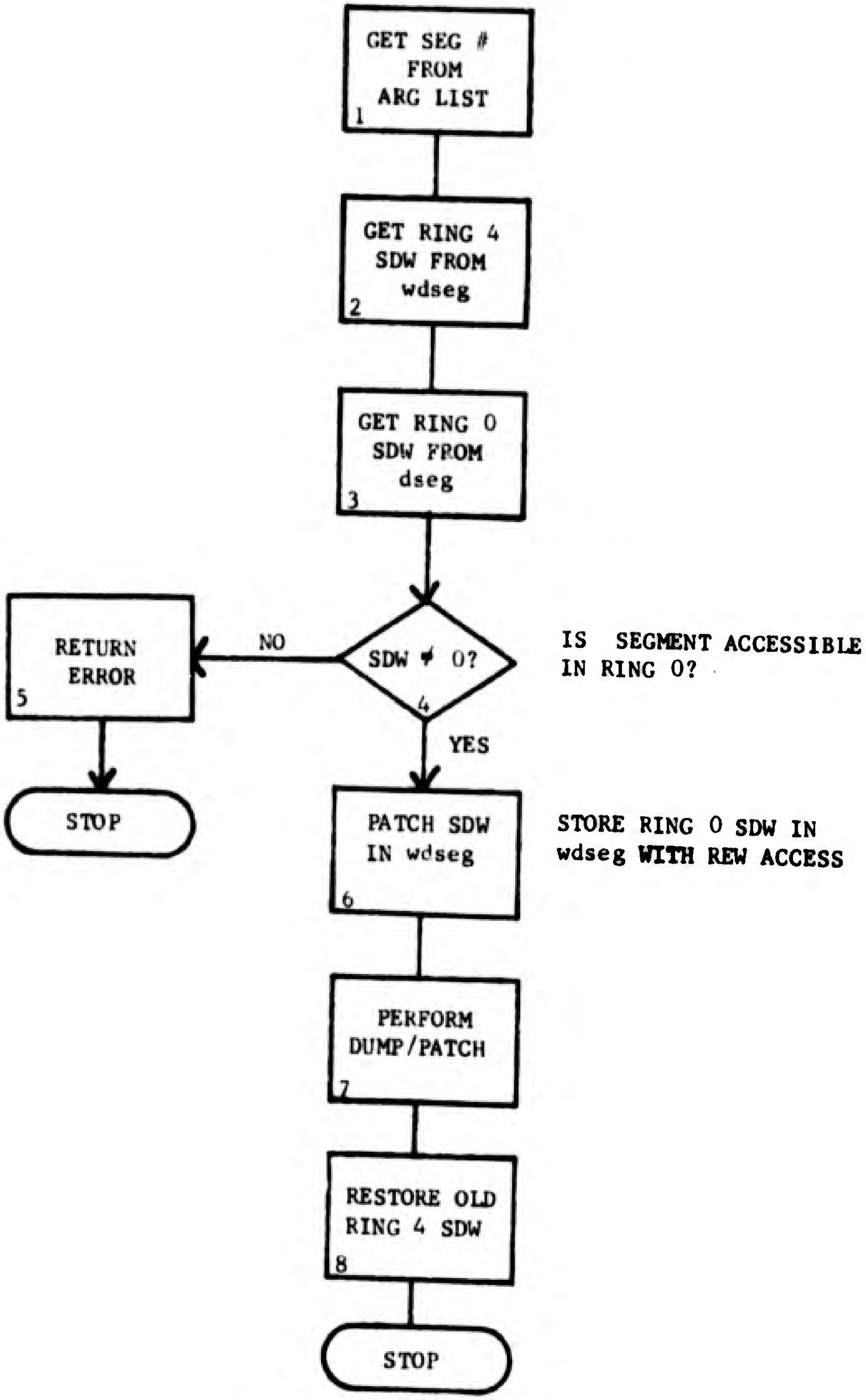


Figure 11. DUMP/PATCH UTILITY USING INSUFFICIENT ARGUMENT VALIDATION

being moved. Finally in block 8, the ring 4 SDW is restored to its original value, so that a later unrelated system crash could not reveal the modified SDW in a dump. It should be noted that while blocks 2, 3, 6, and 8 all use the vulnerability, the bulk of the time is spent in block 7 actually performing the dump or patch in perfectly normal ring 4 slave mode code.

3.4.1.2 Use of Unlocked Stack Base

The Unlocked Stack Base vulnerability operates in a very different environment from the Insufficient Argument Validation vulnerability. Rather than running in ring 0, the Unlocked Stack Base vulnerability runs in ring 4 in master mode. In the ring 0 descriptor segment, the segment dseg is the ring 0 descriptor segment and wdseg is the ring 4 descriptor segment. (26) However, in the ring 4 descriptor segment, the segment dseg is the ring 4 descriptor segment and wdseg has a zeroed SDW. Therefore, a slightly different strategy must be used to implement dump and patch utilities as shown in the flow chart in Figure 12. (27) The primary difference here is in blocks 3 and 5 of Figure 12 in which the ring 4 SDW for the segment is used rather than the ring 0 SDW. Thus the number of segments which can be dumped or patched is reduced from those accessible in ring 0 to those accessible in ring 4 master mode. We shall see in Section 3.4.2 that this reduction is not crucial, since ring 4 master mode has sufficient access to provide "interesting" segments to dump or patch.

3.4.1.3 Generation of New SDW's

Two strategies for implementation of dump and patch utilities were shown above. In addition, a third strategy exists which was rejected due to its inherent dangers. In this third strategy, the penetrator selects an unused segment number and constructs an SDW occupying that segment number in the ring 4 descriptor

(26) Actually wdseg is the descriptor segment for whichever ring (1-7) was active at the time of the entry to ring 0. No conflict occurs since wdseg is <u>always</u> the descriptor segment for the ring on behalf of which ring 0 is operating.

(27) This strategy is also used with the Execute Instruction Access Check Bypass vulnerability which runs in ring 4.

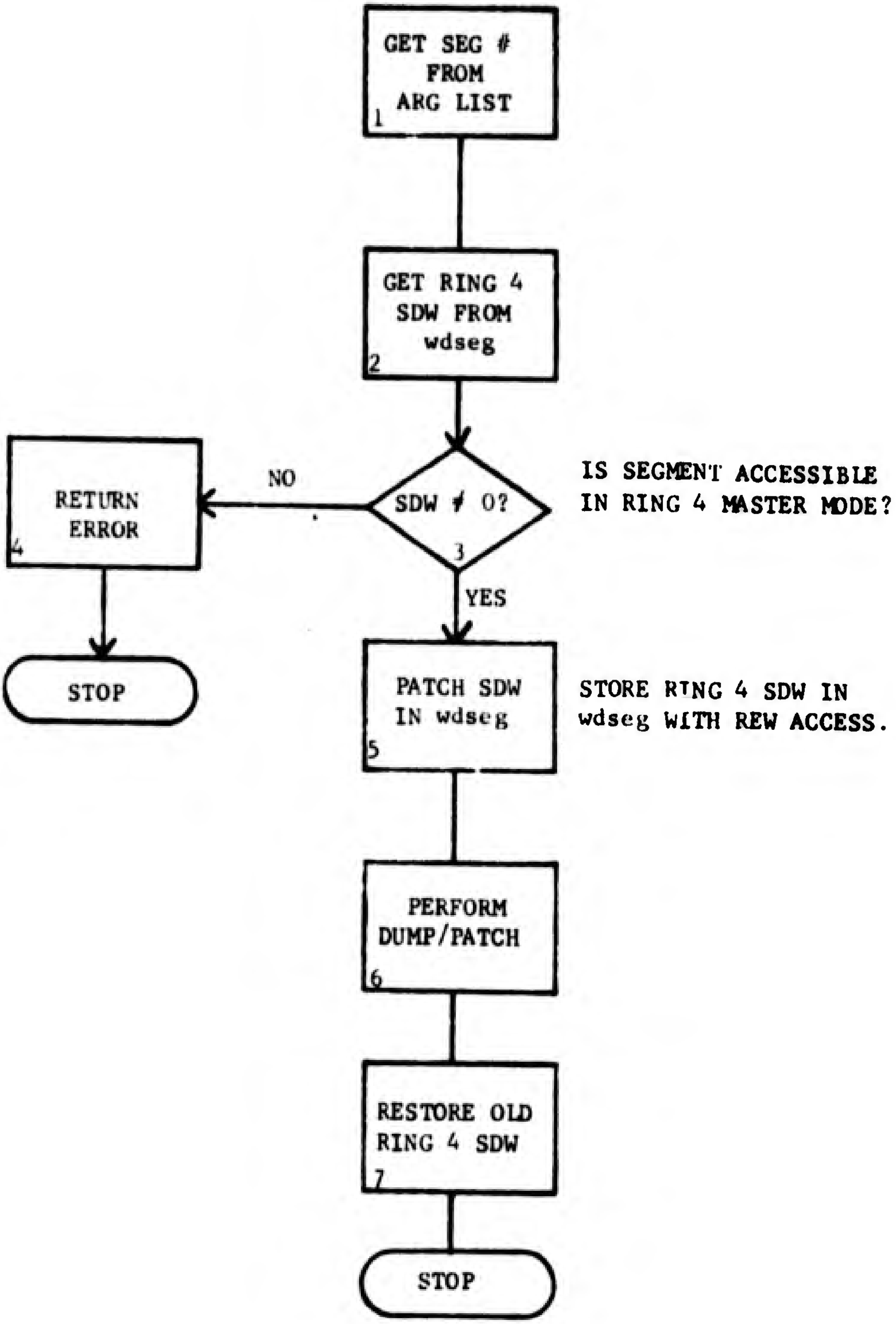


Figure 12. DUMP/PATCH UTILITY USING UNLOCKED STACK BASE

segment using any of the vulnerabilities. This totally new SDW could then be used to access some part of the Multics hierarchy. However, two major problems are associated with this strategy which caused its rejection. First the absolute core address of the page table of the segment must be stored in the SDW address field. There is no easy way for a penetrator to obtain the absolute address of the page table for a segment not already in his descriptor segment short of duplicating the entire segment fault mechanism which runs to many hundreds or thousands of lines of code. Second, if the processor took a segment or page fault on this new SDW, the ring 0 software would malfunction, because the segment would not be recorded in the Known Segment Table (KST). This malfunction could easily lead to a system crash and the disclosure of the penetrator's activities. Therefore, the strategy of generating new SDW's was rejected.

3.4.2 Forging the Non-Forgeable User Identification

In Section 2.2.3 the need for a protected, non-forgeable identification of every user was identified. This non-forgeable ID must be compared with access control list entries to determine whether a user may access some segment. This identification is established when the user logs into Multics and is authenticated by the user password. (28) If this user identification can be forged in any way, then the entire login audit mechanism can be rendered worthless.

The user identification in Multics is stored in a per-process segment called the process data segment (PDS). The PDS resides in ring 0 and contains many constants used in ring 0 and the ring 0 procedure stack. The user identification is stored in the PDS as a character string representing the user's name and a character string representing the user's project. The PDS must be accessible to any ring 0 procedure within a user's process and must be accessible to ring 4 master mode procedures (such as the signaller). Therefore, as shown in Sections 3.4.1.1 and 3.4.1.2, the dump and patch utilities can dump and patch portions of the PDS, thus forging the non-forgeable user identification. Appendix E shows the actual user commands needed to forge the user

(28) Clearly more sophisticated authentication schemes than a single user chosen password could be used on Multics (see Richardson <RIC73>). However, such schemes are outside the scope of this paper.

identification.

This capability provides the penetrator with an "ultimate weapon". The agent can now undetectably masquerade as any user of the system including the system administrator or security officer, immediately assuming that user's access privileges. The agent has bypassed and rendered ineffective the entire login authentication mechanism with all its attendant auditing machinery. The user whom the agent is impersonating can login and operate without interference. Even the "who table" that lists all users currently logged into the system records the agent with his correct identification rather than the forgery. Thus to access <u>any</u> segment in the system, the agent need only determine who has access and change his user identification as easily as a legitimate user can change his working directory.

It was not obvious at the time of the analysis that changing the user identification would work. Several potential problems were forseen that could lead to system crashes or could reveal the penetrator's presence. However, none of these proved to be a serious barrier to masquerading.

First, a user process occasionally sends a message to the operator's console from ring 0 to report some type of unusual fault such as a disk parity error. These messages are prefaced by the user's name and project taken from the PDS. It was feared that a random parity error could "blow the cover" of the penetrator by printing his modified identification on the operator's console. (29) However, the PDS in fact contains two copies of the user identification - one formatted for printing and one formatted for comparison with access control list entries. Ring 0 software keeps these strictly separated, so the penetrator need only change the access control identification.

Second, when the penetrator changes his user identification, he may lose access to his own programs, data and directories. The solution here is to assure that the access control lists of the needed segments and directories grant appropriate access to the user as whom the penetrator is masquerading.

(29) This danger exists only if the operator or system security officer is carefully correlating parity error messages with the names of currently logged in users.

Finally, one finds that although the penetrator can set the access control lists of his ring 4 segments appropriately, he cannot in any easy way modify the access control lists of certain per process supervisor segments including the process data segment (PDS), the process initialization table (PIT), the known segment table (KST), and the stack and combined linkage segments for ring 1, 2, and 3. The stack and combined linkage segments for ring 1, 2, and 3 can be avoided by not calling any ring 1, 2, or 3 programs while masquerading. However, the PDS, PIT, and KST are all ring 0 data bases that must be accessible at all times with read and write permission. This requirement could pose the penetrator a very serious problem; but, because of the very fact that these segments must <u>always</u> be accessible in ring 0, the system has already solved this problem. While the PIT, PDS, and KST are paged segments, (30) they are all used during segment fault handling. In order to avoid recursive segment faults, the PIT, PDS, and KST are never deactivated. (31) Deactivation, as mentioned above, is the process by which a segment's page table is removed from core and a segment fault is placed in its SDW. The access control bits are set in an SDW <u>only</u> at segment fault time. (32) Since the system never deactivates the PIT, PDS, and KST, under normal conditions, the SDW's are not modified for the life of the process. Since the process of changing user identification does not change the ring 0 SDW's of the PIT, PDS, and KST either, the penetrator retains access to these critical segments without any special action whatsoever.

---

(30) In fact the first page of the PDS is wired down so that it may be used by page control. The rest of the PDS, however, is not wired.

(31) In Multics jargon, their "entry hold switches" are set.

(32) In fact, a segment fault is also set in an SDW when the access control list of the corresponding segment is changed. This is done to ensure that access changes are reflected immediately, and is effected by setting faults in all descriptor segments that have active SDW's for the segment. This additional case is not a problem, because the access control lists of the PIT, PDS, and KST are never changed.

3.4.3 Accessing the Password File

One of the classic penetrations of an operating system has been unauthorized access to the password file. This type of attack on a system has become so embedded in the folklore of computer security that it even appears in the definition of a security "breach" in DOD 5200.28-M <DOD73>. In fact, however, accessing the password file internal to the system proves to be of minimal value to a penetrator as shown below. For completeness, the Multics password file was accessed as part of this analysis.

3.4.3.1 Minimal Value of the Password File

It is asserted that accessing the system password file is of minimal value to a penetrator for several reasons. First, the password file is generally the most highly protected file in a computer system. If the penetrator has succeeded in breaking down the internal controls to access the password file, he can almost undoubtedly access *every other file in the system*. Why bother with the password file?

Second, the password file is often kept enciphered. A great deal of effort may be required to invert such a cipher, if indeed the cipher is invertible at all.

Finally, the login path to a system is generally the most carefully audited to attempt to catch unauthorized password use. The penetrator greatly risks detection if he uses an unauthorized password. It should be noted that an unauthorized password obtained outside the system may be very useful to a penetrator, if he does not already have access to the system. However, that is an issue of physical security which is outside the scope of this paper.

3.4.3.2 The Multics Password File

The Multics password file is stored in a segment called the person name table (PNT). The PNT contains an entry for each user on the system including that user's password and various pieces of auditing information. Passwords are chosen by the user and may be changed at any time. (33) Passwords are scrambled by an

(33) There is a major problem that user chosen passwords

allegedly non-invertible enciphering routine for protection in case the PNT appears in a system dump. Only enciphered passwords are stored in the system. The password check at login time is accomplished by the equivalent of the following PL/I code:

```
            if scramble_(typed_password) = pnt.user.password
                then call ok_to_login;
                else call reject_login;
```

For the rest of this section, it will be assumed that the enciphering routine is non-invertible. In a separate volume <DOW74>, Downey demonstrates the invertibility of the Multics password scrambler used at the time of the vulnerability analysis. (34)

The PNT is a ring 4 segment with the following access control list:

```
            rw      *.SysAdmin.*
            null    *.*.*
```

Thus by modifying one's user identification to the SysAdmin project as in Section 3.4.2, one can immediately gain unrestricted access to the PNT. Since the passwords are enciphered, they cannot be read out of the PNT directly. However, the penetrator can extract a copy of the PNT for cryptanalysis. The penetrator can also change a user's password to the enciphered version of a known password. Of course, this action would lead to almost immediate discovery, since the user would no longer be able to login.

3.4.4 Modifying Audit Trails

Audit trails are frequently put into computer systems for the purpose of detecting breaches of security. For example, a record of last login time printed when a user logged in could detect the unauthorized use of a user's password and identification. However, we have seen that a penetrator using vulnerabilities in the operating

are often easy to guess. That problem, however, will not be addressed here. Multics provides a random password generator, but its use is not mandatory.

(34) ESD/MCI has provided a "better" password scrambler that is now used in Multics, since enciphering the password file is useful in case it should appear in a system dump.

system code can access information and bypass many such audits. Sometimes it is not convenient for the penetrator to bypass an audit. If the audit trail is kept online, it may be much easier to allow the audit to take place and then go back and modify the audit trail to remove or modify the evidence of wrong doing. One simple example of modification of audit trails was selected for this vulnerability demonstration.

Every segment in Multics carries with it audit information on the date time last used (DTU) and date time last modified (DTM). These dates are maintained by an audit mechanism at a very low level in the system, and it is almost impossible for a penetrator to bypass this mechanism. (35) An obvious approach would be to attempt to patch the DTU and DTM that are stored in the parent directory of the segment in question. However, directories are implemented as rather complex hash tables and are therefore very difficult to patch.

Once again, however, a solution exists within the system. A routine called set_dates is provided among the various subroutine calls into ring 0 which is used when a segment is retrieved from a backup tape to set the segment's DTU and DTM to the values at the time the segment was backed up. The routine is supposed to be callable only from a highly privileged gate into ring 0 that is restricted to system maintenance personnel. However, since a penetrator can change his user identification, this restriction proves to be no barrier. To access a segment without updating DTU or DTM:

1. Change user ID to access segment.
2. Remember old DTU and DTM.
3. Use or modify the segment.
4. Change user ID to system maintenance.
5. Reset DTU and DTM to old values.
6. Change user ID back to original.

In fact due to yet another system bug, the procedure is even easier. The module set_dates is callable, not only from the highly privileged gate into ring 0, but also from the normal user gate into ring 0. (36) Therefore, step 4

(35) Section 3.4.5 shows a motivation to bypass DTU and DTM.

(36) The user gate into ring 0 contains set_dates, so that users may perform reloads from private backup tapes.

in the above algorithm can be omitted if desired. A listing of the utility that changes DTU and DTM may be found in Appendix F.

It should be noted that one complication exists in step 5 - resetting DTU and DTM. The system does not update the dates in the directory entry immediately, but primarily at segment deactivation time. (37) Therefore, step 5 must be delayed until the segment has been deactivated - a delay of up to several minutes. Otherwise the penetrator could reset the dates, only to have them updated again a moment later.

3.4.5 Trap Door Insertion

Up to this point, we have seen how a penetrator can exploit existing weaknesses in the security controls of an operating system to gain unauthorized access to protected information. However, when the penetrator exploits existing weaknesses, he runs the constant risk that the system maintenance personnel will find and correct the weakness he happens to be using. The penetrator would then have to begin again looking for weaknesses. To avoid such a problem and to perpetuate access into the system, the penetrator can install "trap doors" in the system which permit him access, but are virtually undetectable.

3.4.5.1 Classes of Trap Doors

Trap doors come in many forms and can be inserted in many places throughout the operational life of a system from the time of design up to the time the system is replaced. Trap doors may be inserted at the facility at which the system is produced. Clearly if one of the system programmers is an agent, he can insert a trap door in the code he writes. However, if the production site is a (perhaps on-line) facility to which the penetrator can gain access, the penetrator can exploit existing vulnerabilities to insert trap doors into system software while the programmer is still working on it or while it is in quality assurance.

As a practical example, it should be noted that the software for WWMCCS is currently developed using uncleared personnel on a relatively open time sharing system at Honeywell's plant in Phoenix, Arizona.

(37) Dates may be updated at other times as well.

The software is monitored and distributed from an open time sharing system at the Joint Technical Support Agency (JTSA) at Reston, Virginia. Both of these sites are potentially vulnerable to penetration and trap door insertion.

Trap doors can be inserted during the distribution phase. If updates are sent via insecure communications - either US Mail or insecure telecommunications, the penetrator can intercept the update and subtly modify it. The penetrator could also generate his own updates and distribute them using forged stationery.

Finally, trap doors can be inserted during the installation and operation of the system at the user's site. Here again, the penetrator uses existing vulnerabilities to gain access to stored copies of the system and make subtle modifications.

Clearly when a trap door is inserted, it must be well hidden to avoid detection by system maintenance personnel. Trap doors can best be hidden in changes to the binary code of a compiled routine. Such a change is completely invisible on system listings and can be detected only by comparing bit by bit the object code and the compiler listing. However, object code trap doors are vulnerable to recompilations of the module in question.

Therefore the system maintenance personnel could regularly recompile all modules of the system to eliminate object code trap doors. However, this precaution could play directly into the hands of the penetrator who has also made changes in the source code of the system. Source code changes are more visible than object code changes, since they appear in system listings. However, subtle changes can be made in relatively complex algorithms that will escape all but the closest scrutiny. Of course, the penetrator must be sure to change all extant copies of a module to avoid discovery by a simple comparison program.

Two classes of trap doors which are themselves source or object trap doors are particularly insidious and merit discussion here. These are the teletype key string trigger trap door and the compiler trap door.

It has often been hypothesized that a carefully written closed subsystem such as a query system or limited data management system without programming capabilities may be made invulnerable to security penetration. The teletype key string trigger is just one example of a trap door that provides the penetrator with a vulnerability in even the most limited subsystem. To create such a trap door, the agent modifies the supervisor teletype modules at the development site such that if the user types normally, no anomaly occurs, but if the user types a special key string, a dump/patch utility is triggered into operation to allow the penetrator unlimited access. The key string would of course have to be some very unlikely combination to avoid accidental discovery. The teletype key string trap door is somewhat more complex than the trap door described below in Section 3.4.5.2. However, it is quite straightforward to develop and insert with relatively nominal effort.

It was noted above that while object code trap doors are invisible, they are vulnerable to recompilations. The compiler (or assembler) trap door is inserted to permit object code trap doors to survive even a complete recompilation of the entire system. In Multics, most of the ring 0 supervisor is written in PL/I. A penetrator could insert a trap door in the PL/I compiler to note when it is compiling a ring 0 module. Then the compiler would insert an object code trap door in the ring 0 module without listing the code in the listing. Since the PL/I compiler is itself written in PL/I, the trap door can maintain itself, _even when the compiler is recompiled_. (38) Compiler trap doors are significantly more complex than the other trap doors described here, because they require a detailed knowledge of the compiler design. However, they are quite practical to implement at a cost of perhaps five times the level shown in Section 3.5. It should be noted that even costs several hundred times larger than those shown here would be considered nominal to a foreign agent.

There is also a variant on the compiler trap door called the initialization trap door. Here, the system initialization code is modified by the penetrator to insert other trap doors as the system is brought up. Such trap doors can be relatively invulnerable to

(38) This type of trap door does not require a higher level language. Entirely analogous trap doors could be placed in an assembler.

detection and recompilation, because system initialization is usually a very complex and poorly understood procedure.

3.4.5.2 Example of a Trap Door in Multics

To demonstrate the feasibility of inserting and distributing trap doors, the following object code change was made to check$device_name to provide a generalized dump or patch facility. Figure 13 shows a PL/I program that performs essentially the same function as the trap door actually inserted in the object code. The listing of the actual trap door and its calling program is in Appendix C. Check$device_name is normally called with three arguments, the third being a fixed binary error code. The trap door is inserted at the point at which check$device_name would have returned. The trap door looks at the 72 bits immediately following the error code that was passed by the caller. If those 72 bits match a predefined 72 bit password, then the fixed binary word to which ptr1 points is copied into the fixed binary word to which ptr2 points. Since check$device_name is a ring 0 procedure, this copy is carried out using the ring 0 descriptor segment and allows the caller to read or write any word in ring 0. Dump and patch utilities can use this trap door exactly like the Insufficient Argument Validation vulnerability. The 72 bit key is used to ensure that the vulnerability is not invoked by accident by some unsuspecting user.

The actual insertion of the trap door was done by the following steps:

1. Change user identification to project SysLib.

2. Make patch in object archive copy of check$device_name in >ldd>hard>object.

3. Reset DTM on object archive.

4. Make patch in bound archive copy of check$device_name in >ldd>hard>bound_components.

5. Reset DTM on bound archive.

6. Reset user identification.

This procedure ensured that the object patch was in all library copies of the segment. The DTM was reset as in Section 3.4.4, because the dates on library segments are

```
check$device_name: procedure (a, b, code);

declare   1 code parameter,
                2 err_code fixed binary (35),
                2 key bit (72) aligned,
                2 ptr1 pointer aligned,
                2 ptr2 pointer aligned;

declare overlay fixed binary (35) based;


/*  Start of regular code  */

          ...;

/*  Here check$device_name would normally return  */


          if key = bit_string_constant_password
               then ptr2 -> overlay = ptr1 -> overlay;


          return;

     end check$device_name;
```

Figure 13.   Trapdoor in check$device_name

checked regularly for unauthorized modification. These operations did not immediately install the trap door. Actual installation occurred at the time of the next system tape generation.

A trap door of this type was first placed in the Multics system at MIT in the procedure del_dir_tree. However, it was noted that del_dir_tree was going to be modified and recompiled in the installation of Multics system 18.0. Therefore, the trap door described above was inserted in check$device_name just before the installation of 18.0 to avoid the recompilation problem. Honeywell was briefed in the spring of 1973 on the results of this vulnerability analysis. At that time, Honeywell recompiled check$device_name, so that the trap door would not be distributed to other sites.

3.4.6 Preview of 6180 Procedural Vulnerabilities

To actually demonstrate the feasibility of trap door distribution, a change which could have included a trap door was inserted in the Multics software that was transferred from the 645 to the 6180 at MIT and from there to all 6180 installations in the field.

3.5 Manpower and Computer Costs

Table III outlines the approximate costs in man-hours and computer charges for each vulnerability analysis task. The skill level required to perform the penetrations was that of a recent computer science graduate of any major university with a moderate knowledge of the Multics design documented in the _Multics Programmers' Manual_ <MPM73> and Organick <ORG72>, plus nine months experience as a Multics programmer. In addition, the penetrator was aided by access to the system listings (which are in the public domain) and access to an operational Multics system on which to debug penetrations. In this example, the RADC system was used to test penetrations prior to their use at MIT, since a system crash at MIT would reveal the intentions of the penetrations. (39)

Costs are broken down into identification, confirmation, and exploitation. Identification is that

(39) It should be noted that while the MIT system was crashed twice due to typographical errors during the penetration, the RADC system was never crashed.

part of the effort needed to identify a particular vulnerability. It generally involves examination of system listings, although it sometimes involves computer work. Confirmation is that effort needed to confirm the existence of a vulnerability by using it in some manner, however crude, to access information without authorization. Exploitation is that effort needed to develop and debug command procedures to make use of the vulnerabilities convenient. Wherever possible, these command procedures follow standard Multics command conventions.

All figures in the table are conservative estimates as actual accounting information was not kept during the vulnerability analysis. However, costs did not exceed the figures given and in all probability were somewhat lower.

The costs of implementing the subverter and inverting the password scrambler are not included, because those tasks were not directly related to penetrating the system (See Downey <DOW74>). The Master Mode Transfer vulnerability has no exploitation cost shown, because that vulnerability was not carried beyond confirmation.

TABLE 3

Cost Estimates

Task	Identification		Confirmation		Exploitation		Total	
	Manhrs	CPU $	Manhrs	CPU $	Manhrs	CPU $	Manhrs	CPU $
Execute Instruction Access Check Bypass	60	$150	5	$ 30	8	$100	73	$280
Insufficient Argument Validation	1	$ 0	5	$ 30	24	$300	30	$330
Master Mode Transfer	0.5	$ 0	2	$ 20	--	---	2.5	$ 20
Unlocked Stack Base	0.5	$ 0	8	$ 50	80	$500	88.5	$550
Forging User ID	5	$ 0	5	$ 30	5	$ 90	15	$120
check$device_name Trap door	5	$ 0	8	$ 50	5	$ 30	18	$ 80
Access Password File (Does not include deciphering.)	1	$ 0	5	$ 30	24	$150	30	$180
Total	73	$150	38	$240	146	$1170	257	$1560

SECTION IV

CONCLUSIONS

The initial implementation of Multics is an instance of an uncertified system. For any uncertified system:

a. The system cannot be depended upon to protect against deliberate attack.

b. System "fixes" or restrictions (e.g., query only systems) cannot provide any significant improvement in protection. Trap door insertion and distribution has been demonstrated with minimal effort and fewer tools (no phone taps) than any industrious foreign agent would have.

However, Multics is significantly better than other conventional systems due to the structuring of the supervisor and the use of segmentation and ring hardware. Thus, unlike other systems, Multics can form a base for the development of a truly secure system.

4.1 Multics is not Now Secure

The primary conclusion one can reach from this vulnerability analysis is that Multics is not currently a secure system. A relatively low level of effort gave examples of vulnerabilities in hardware security, software security, and procedural security. While all the reported vulnerabilities were found in the HIS 645 system and happen to be fixed by the nature of the changes in the HIS 6180 hardware, other vulnerabilities exist in the HIS 6180. (40) No attempt was made to find more than one vulnerability in each area of security. Without a doubt, vulnerabilities exist in the HIS 645 Multics that have not been identified. Some major areas not even examined are I/O, process management, and administrative interfaces. Further, an initial cursory examination of the HIS 6180 Multics easily turned up vulnerabilities.

We have seen the impact of implementation errors or omissions in the hardware vulnerability. In the

(40) In all fairness, the HIS 6180 does provide significant improvements by the addition of ring hardware. However, ring hardware by itself does not make the system secure. Only certification as a well-defined closed process can do that.

software vulnerabilities, we have seen the major security impact of apparently unimportant ad hoc designs. We have seen that the development site and distribution paths are particularly attractive for penetration. Finally, we have seen that the procedural controls over such areas as passwords and auditing are no more than "security blankets" as long as the fundamental hardware and software controls do not work.

4.2 Multics as a Base for a Secure System

While we have seen that Multics is not now a secure system, it is in some sense significantly "more secure" than other commercial systems and forms a base from which a secure system can be developed. (See Lipner <LIP74>.) The requirements of security formed part of the basic guiding principles during the design and implementation of Multics. Unlike systems such as OS/360 or GCOS in which security functions are scattered throughout the entire supervisor, Multics is well structured to support the identification of the security and non-security related functions. Further Multics possesses the segmentation and ring hardware which have been identified <SMI74> as crucial to the implementation of a reference monitor.

4.2.1 A System for a Benign Environment

We have concluded that AFDSC cannot run an open multi-level secure system on Multics at this time. As we have seen above, a malicious user can penetrate the system at will with relatively minimal effort. However, Multics does provide AFDSC with a basis for a <u>benign</u> multi-level system in which all users are determined to be trustworthy to some degree. For example, with certain enhancements, Multics could serve AFDSC in a two-level security mode with both Secret and Top Secret cleared users simultaneously accessing the system. Such a system, of course, would depend on the administrative determination that since <u>all</u> users are cleared at least to Secret, there would be no malicious users attempting to penetrate the security controls.

A number of enhancements are required to bring Multics up to a two-level capability. First and most important, all segments, directories, and processes in the system should be labeled with classification levels and categories. This labeling permits the classification check to be combined with the ACL check and to be represented in the descriptor segment. Second, an earnest review of the Multics operating system is needed to identify vulnerabilities. Such a review is meaningful in Multics, because of its well structured operating system design. A similar review would be a literally endless task in a system such as OS/360 or GCOS. A review of Multics should include an identification of security sensitive modules, an examination of all gates and arguments into ring 0, and a check of all intersegment references in ring 0. Two additional enhancements would be useful but not essential. These are some sort of "high water mark" system as in ADEPT-50 (see Weissman <WEI69>) and some sort of protection from user written applications programs that may contain "Trojan Horses".

4.2.2 Long Term Open Secure System

In the long term, it is felt that Multics can be developed into an open secure multi-level system by restructuring the operating system to include a security kernel. Such restructuring is essential since malicious users cannot be ruled out in an open system. The procedures for designing and implementing such a kernel are detailed elsewhere. <AND73, BL73-1, BL73-2, LIP73, PRI73, SCH73, SCHI73, WAL74> To briefly summarize, the access controls of the kernel must always be invoked (segmentation hardware); must be tamperproof (ring hardware); and must be small enough and simple enough to be certified correct (a small ring 0). Certifiability is the critical requirement in the development of a multi-level secure system. ESD/MCI is currently proceeding with a development plan to develop such a certifiably secure version of Multics <ESD73>.

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APPENDIX A

Subverter Listing

This appendix contains listings of the three program modules which make up the hardware subverter described in Section 3.2.1. The three procedure segments which follow are called subverter, coded in PL/I; access_violations_, coded in PL/I; and subv, coded in assembler. Subverter is the driving routine which sets up timers, manages free storage, and calls individual tests. Access_violations_ contains several entry points to implement specific tests. Subv contains entry points to implement those tests which must be done in assembler.

The internal procedure check_zero within subverter is used to watch word zero of the procedure segment for unexpected modification. This procedure was used in part to detect the Execute Instruction Access Check Bypass vulnerability.

The errors flagged in the listing of subv are all warnings of obsolete 645 instructions, because the attached listing was produced on the 6180.

```
COMPILATION LISTING OF SEGMENT subverter
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1845.8 edt Wed
    Options: map



 sjbverter:
     procedure;

          declare
               hcs_$initiate entry (char (*), char (*), char (*), fixed bin (1), fixed bin (2), ptr, fixed bin),
               date_time_ entry (fixed bin (71), char (*)),
               default_handler_$set entry (entry),          /* establishes default condition handler */
               timer_manager_$alarm_call_inhibit entry (fixed bin (71), bit (2), entry),
                                                            /* sets alarm clocks */
               timer_manager_$reset_alarm_call entry (entry),
                                                            /* resets alarm clocks */
               hcs_$make_seg entry (char (*), char (*), char (*), fixed bin (5), ptr, fixed bin),
                                                            /* create a segment */
               user_info_$homedir entry (char (*)),
               cu_$arg_ptr entry (fixed bin, ptr, fixed bin, fixed bin),
                                                            /* get pointer to arguments */
               com_err_ entry options (variable),           /* prints error messages */
               ioa_$ioa_stream entry options (variable),    /* prints on io streams */
               ioa_ entry options (variable),               /* prints on user_output */
               cv_dec_check_ entry (char (*), fixed bin) returns (fixed bin (35)),
                                                            /* string to numeric conversion */
               subverter$timer ext entry,                   /* entry to do the testing */
              (     subv$cam,                               /* does a cam instruction */
                    subv$idt,
                    subv$idbr,
                    subv$sdbr,
                    subv$cioc,
                    subv$dis,
                    subv$rmcm,
                    subv$smcm,
                    subv$smic,
                    subv$lacl,
                    subv$lam,
                    subv$sam,
                    subv$rcu,
                    subv$scu,
                    access_violations_$illegal_opcodes,
                    access_violations_$fetch,
                    access_violations_$store,
                    access_violations_$xed_fetch,
                    access_violations_$xed_store,
                    access_violations_$id,
                    access_violations_$legal_bounds_fault,
                    access_violations_$illegal_bounds_fault)
               entry (ptr),
               clock_ entry returns (fixed bin (71));
          declare
               i fixed bin,
               fp pointer,                                  /* points to failure blocks */
               sp pointer int static,                       /* points to statistics segment */
               code fixed bin,
               wdir char (168),
               dt_string char (24),
                arg char (argl) based (argp),
                argl fixed bin,
                argp pointer,
                error_table_$badopt fixed bin (35) ext static,
                seg_version fixed bin int static init (1),
                max_test fixed bin int static init (22),
                test_names (22) int static char (32) init ("cam", "scu", "ldt", "ldbr", "sdbr", "cioc", "dis",
                     "rmcm", "smcm", "smic", "lacl", "lam", "sam", "rcu", "fetch_access_violation",
                     "store_access_violation", "xed_fetch_access_violation", "xed_store_access_violation",
                     "it_access_violation", "legal_bounds_fault", "illegal_bounds_fault", "illegal_opcode"),
                ret_label label int static,
                interval fixed bin (35) int static,
                time fixed bin (71);

/* start of include file subvert_statistics.incl.pl1

          Initially coded by 2 Lt. Paul Karger  19 July 1972 0900 */


          declare

          1 subvert_statistics based(sp) aligned,
               2 cur_test fixed bin(17) unal,                /* number of current test in progress */
               2 next_code fixed bin(17) unal,               /* next opcode number */
               2 end_of_segment fixed bin(17) unal,                    /* rel pointer to end of segment */
               2 last_failure_block fixed bin(17) unal,      /* rel pointer to last failure block used */
               2 test_in_progress fixed bin,                 /* test number of test in progress
                                                                = 0 if no test in progress
                                                                identifies test in progress if machine crashes */
               2 time_of_last_test fixed bin(71),
               2 cum_total_time fixed bin(71),
               2 number_of_tests fixed bin,
               2 tests(i refer(number_of_tests)) aligned,
                    3 number_of_attempts fixed bin,          /* number of attempts of this test */
                    3 number_of_failures fixed bin,          /* number of machine or software failures found */
                    3 failure_block_ptr fixed bin(17) unal, /* rel pointer to start of threaded list of failure blocks */
                    3 last_test_time fixed bin(71),
                    3 cum_test_time fixed bin(71);

/* End of subvert_statistics.incl.pl1 */

/* Start of include file failure_block.incl.pl1

          Initially coded by 2 Lt. Paul Karger    19 July 1972   0900 */
/*        Modified 21 July 72 0820 by P. Karger to use fixed bin unal

                                                   */


          declare

          1 failure_block based(fp) aligned,
               2 version fixed bin,                          /* version number = 1 */
               2 type fixed bin,                             /* index of test in test array */
               2 time_of_failure fixed bin(71),
               2 next_block fixed bin(17) unal,              /* rel pointer to next failure block of this type */
               2 scu_data(5) fixed bin;            /* to be defined */

```

```
/* End of include file failure_block.incl.pl1 */

          interval = 60;                                    /* default interval = 60 seconds */
          call cu_$arg_ptr (1, argp, argl, code);
          if code = 0 then
               do;
                    if arg = "-stop" then
                         do;
                              call timer_manager_$reset_alarm_call (subverter$timer);
                              return;
                         end;
                    interval = cv_dec_check_ (arg, code);
                    if code ^= 0 then
                         do;
                              call com_err_ (error_table_$badopt, "subverter", arg);
                              return;
                         end;
               end;
          call user_info_$homedir (wdir);
          call hcs_$make_seg (wdir, "subvert_statistics", "", 01011b, sp, code);
          if sp = null () then
               do;
no_seg:
                    call com_err_ (code, "subverter", "subvert_statistics");
                    return;
               end;
          if code = 0 then
               do;                                          /* segment is new */
                    last_failure_block, end_of_segment = 10000000000000000b;
                                                            /* 64K segment length */
                    number_of_tests = max_test;
                    cur_test = 1;
                    next_code = -1;
               end;
          else
               do;                                          /* segment already exists */
                    if test_in_progress ^= 0 then
                         do;
                              call com_err_ (0, "subverter",
                                   "Test ^a was in progress.  Call subverter$reset to clear segment and resume.",
                                   test_names (test_in_progress));
                              return;
                         end;
               end;

finish_setup:
          time_of_last_test = clock_ ();
          do i = 1 to number_of_tests;
               last_test_time (i) = time_of_last_test;
          end;
          call timer_manager_$alarm_call_inhibit (1, "11"b, subverter$timer);
                                                            /* start in 1 second */
          return;


subverter$reset:
    entry;
          if test_in_progress = 22 /* illegal opcode test */ then next_code = next_code - 1;
          test_in_progress = 0;
          go to finish_setup;


sjbverter$timer:
     entry ();
          call check_zero ();
          ret_label = next_setup;
          call default_handler_$set (fault_handler);
          call get_failure_block (cur_test);
          number_of_attempts (cur_test) = number_of_attempts (cur_test) + 1;
          time = clock_ ();
          cum_total_time = cum_total_time + time - time_of_last_test;
          time_of_last_test = time;
          cum_test_time (cur_test) = cum_test_time (cur_test) + time - last_test_time (cur_test);
          last_test_time (cur_test) = time;
          go to c (cur_test);

c (1):
          call subv$cem (fp);
          go to scream_bloody_murder;

c (2):
          call subv$scu (fp);
          go to scream_bloody_murder;


c (3):
          call subv$idt (fp);
          go to scream_bloody_murder;


c (4):
          call subv$idbr (fp);
          go to scream_bloody_murder;


c (5):
          call subv$sdbr (fp);
          go to scream_bloody_murder;


c (6):
          call subv$cioc (fp);
          go to scream_bloody_murder;


c (7):
          call subv$dis (fp);
          go to scream_bloody_murder;


c (8):
          call subv$rmcm (fp);
          go to scream_bloody_murder;


c (9):
          call subv$smcm (fp);
          go to scream_bloody_murder;
```

```


c (10):
          call subv$ssic (fp);
          go to scream_bloody_murder;


c (11):
          call subv$lacl (fp);
          go to scream_bloody_murder;


c (12):
          call subv$lee (fp);
          go to scream_bloody_murder;


c (13):
          call subv$see (fp);
          go to scream_bloody_murder;


c (14):
          call subv$rcu (fp);
          go to scream_bloody_murder;


c (15):
          call access_violations_$fetch (fp);
          go to scream_bloody_murder;


c (16):
          call access_violations_$store (fp);
          go to scream_bloody_murder;


c (17):
          call access_violations_$xed_fetch (fp);
          go to scream_bloody_murder;


c (18):
          call access_violations_$xed_store (fp);
          go to scream_bloody_murder;


c (19):
          call access_violations_$id (fp);
          go to scream_bloody_murder;


c (20):
          call access_violations_$legal_bounds_fault (fp);
          go to scream_bloody_murder;


c (21):
          call access_violations_$illegal_bounds_fault (fp);
          go to scream_bloody_murder;


c (22):
          call access_violations_$illegal_opcodes (fp);
          go to scream_bloody_murder;


scream_bloody_murder:
          number_of_failures (cur_test) = number_of_failures (cur_test) + 1;
          call ioa_$ioa_stream ("error_output",
               "^/***************^/From subverter:  Test ^R^a^B succeeded!^/***************", test_names (cur_test)
                );
          test_in_progress = 0;

next_setup:
          call check_zero ();
          if cur_test = max_test then cur_test = 1;
          else cur_test = cur_test + 1;
          time = interval;
          call timer_manager_$alarm_call_inhibit (time, "11"b, subverter$timer);
          return;


display:
     entry ();
          call user_info_$homedir (wdir);
          call hcs_$initiate (wdir, "subvert_statistics", "", 0, 0, sp, code);
          if sp = null () then go to no_seg;


          call ioa_ ("^/^/^-Display of subverter statistics.^/");
          if test_in_progress ^= 0 then call ioa_ ("Test ^R^a^B in progress.", test_names (test_in_progress));

          call ioa_ ("Total testing time = ^.2f hours.", cum_total_time/3600000000.0e0);
          call ioa_ ("^-^-^-Cumulative");
          call ioa_ ("Test Name ^-^-Test  Time  Attempts  Failures");
          do i = 1 to number_of_tests;
               call ioa_ ("^30a  ^8.2f  ^8d  ^8d", test_names (i), cum_test_time (i)/3600000000.0e0,
                    number_of_attempts (i), number_of_failures (i));
               do fp = pointer (sp, failure_block_ptr (i)) repeat (pointer (sp, next_block)) while (rel (fp) ^=
                    "0"b);
                    call date_time_ (time_of_failure, dt_string);
                    call ioa_ ("^-^-Failure at ^a.", dt_string);
               end;
          end;
          return;

get_failure_block:
          proc (i);

               declare
                    block_size (22) fixed bin init ((22) 32) int static,
                    i fixed bin (17) unal,
                    p ptr,
                    fp ptr;
               do p = pointer (sp, failure_block_ptr (i)) repeat (pointer (sp, fp -> next_block)) while (rel (p)
                    ^= "0"b);
                    fp = p;
```

```
              end;
              if failure_block_ptr (i) ^= 0 then
                   do;                                    /* there already exists >= 1 failure blocks for this type */
                        fp -> next_block, last_failure_block = last_failure_block - block_size (i);
                                                          /* thread on new block */
                        fp = pointer (sp, fp -> next_block);
                                                          /* set the pointer to the new block */
                   end;
              else
                   do;                                    /* this is the first failure block for this test type */
                        failure_block_ptr (i), last_failure_block = last_failure_block - block_size (i);
                                                          /* thread on the block */
                        fp = pointer (sp, failure_block_ptr (i));
                                                          /* set the pointer */
                   end;
              fp -> failure_block.version = seg_version;   /* initialize the block */
              fp -> type = i;
              return;


free_failure_block:
         entry (i);                                       /* entry to free space from an unneeded failure block */
              fp -> failure_block.version, fp -> type = 0; /* zero the data */
              do p = pointer (sp, failure_block_ptr (i)) repeat (pointer (sp, p -> next_block)) while (rel (p) ^=
                   rel (fp));
                   fp = p;                                /* find a pointer to the block just before the one to be freed. */
              end;
              if p ^= pointer (sp, failure_block_ptr (i)) then fp -> next_block = 0;
                                                          /* if not first block then unthread from block before */
              else failure_block_ptr (i) = 0;             /* else unthread from header */
              last_failure_block = last_failure_block + block_size (i);
                                                          /* indicate space is free */
         end;



fault_handler:
         procedure (mc_ptr, cond_name, wc_ptr, info_ptr, continue);
                                                          /* procedure to catch interrupts */
              declare
                   (      mc_ptr,                         /* pointer to saved machine conditions */
                          wc_ptr,                         /* pointer to machine conditions in ring 0 */
                          info_ptr)                       /* pointer to software defined info */
                   ptr,
                   cond_name char (*),                    /* name of condition */
                   i fixed bin,
                   n_conds fixed bin int static init (8),
                   continue bit (1) aligned,              /* bit to indicate to continue search for handler */
                   conds (8) char (32) int static init ("illegal_procedure", "635/645_compatibility",
                        "635_compatibility", "undefined_acc", "accessviolation", "bounds_fault_ok",
                        "out_bounds_err", "illegal_opcode") ;
                                                          /* array of cond names */
              do i = 1 to n_conds;                        /* loop through the condition name array */
                   if cond_name = conds (i) then
                        do;                               /* we want this condition */
                             test_in_progress = 0;        /* No more worries about crashes */
                             call free_failure_block (cur_test);
                                                          /* free the failure block */
                             go to ret_label;             /* non-local goto */
```

```
          end;
      end;
      continue = "1"b;
      return;                                       /* We can't handle this condition */
    end;                                            /* so maybe someone else can... */
check_zero:
    proc;
                                                    /* This is a procedure to check for clobbering of bound_subverter
*/
      declare
        1 impure based (impure_ptr) aligned,
          2 lock_word bit (36) aligned,
          2 compare_word bit (36) aligned;
      declare
        word_zero bit (36) aligned based (pointer (impure_ptr, 0)),
        impure_ptr pointer based (addr (label_var)),
        label_var label,
        exec_com entry options (variable),
        setacl entry options (variable);
      label_var = dummy_label;
      if lock_word ^= "0"b then
        do;
          call setacl (">udd>d>pak>subverter", "rew", "Karger.Druid.*");
          compare_word = word_zero;
          lock_word = "0"b;
          call setacl (">udd>d>pak>subverter", "re", "Karger.Druid.*");
        end;
      else
        if compare_word ^= word_zero then call exec_com (">udd>Druid>Karger>subverter_error",
          test_names (cur_test));
        return;
dummy_label:

        i = i + 1;
        i = i + 1;
    end;
  end;
```

```
        INCLUDE FILES USED IN THIS COMPILATION.

   LINE      NUMBER     NAME                                    PATHNAME
     70           1     subvert_statistics.incl.pl1             >user_dir_dir>Druid>Karger>compiler_pool>subvert_statistics.incl.pl1
     71           2     failure_block.incl.pl1                  >user_dir_dir>Druid>Karger>compiler_pool>failure_block.incl.pl1
```

```
        NAMES DECLARED IN THIS COMPILATION.

IDENTIFIER                  OFFSET   LOC STORAGE CLASS    DATA TYPE         ATTRIBUTES AND REFERENCES

NAMES DECLARED BY DECLARE STATEMENT.
access_violations_$fetch
                                    000374 constant          entry             external dcl 7 ref 215
access_violations_$id
                                    000404 constant          entry             external dcl 7 ref 235
access_violations_$illegal_bounds_fault
                                    000410 constant          entry             external dcl 7 ref 245
access_violations_$illegal_opcodes
                                    000372 constant          entry             external dcl 7 ref 250
access_violations_$legal_bounds_fault
                                    000406 constant          entry             external dcl 7 ref 240
access_violations_$store
                                    000376 constant          entry             external dcl 7 ref 220
access_violations_$xed_fetch
                                    000400 constant          entry             external dcl 7 ref 225
access_violations_$xed_store
                                    000402 constant          entry             external dcl 7 ref 230
arg                                        based             char              unaligned dcl 58 set ref 76 81 84
argl                                000165 automatic         fixed bin(17,0)   dcl 58 set ref 73 76 81 81 84 84
argp                                000166 automatic         pointer           dcl 58 set ref 73 76 81 84
block_size                          000126 constant          fixed bin(17,0)   initial array dcl 299 ref 309 316 336
clock_                              000412 constant          entry             external dcl 7 ref 115 139
code                                000104 automatic         fixed bin(17,0)   dcl 58 set ref 73 74 81 82 89 92 96 274
com_err_                            000324 constant          entry             external dcl 7 ref 84 92 100
compare_word                     1         based             bit(36)           level 2 dcl 373 set ref 386 391
cond_name                                  parameter         char              unaligned dcl 346 ref 342 359
conds                               000026 constant          char(32)          initial array unaligned dcl 346 ref 359
continue                                   parameter         bit(1)            dcl 346 set ref 342 367
cu_$arg_ptr                         000322 constant          entry             external dcl 7 ref 73
cum_test_time                   20         based             fixed bin(71,0)   array level 3 dcl 1-7 set ref 142 142 205
cum_total_time                   6         based             fixed bin(71,0)   level 2 dcl 1-7 set ref 148 148 201
cur_test                                   based             fixed bin(17,0)   level 2 packed unaligned dcl 1-7 set ref 101 137
                                                                               138 138 142 142 142 143 144 255 255 257 264 264
                                                                               265 265 342 391
cv_dec_check_                       000332 constant          entry             external dcl 7 ref 81
date_time_                          000306 constant          entry             external dcl 7 ref 289
default_handler_$set                000310 constant          entry             external dcl 7 ref 136
dt_string                           000157 automatic         char(24)          unaligned dcl 58 set ref 289 290
end_of_segment                   1         based             fixed bin(17,0)   level 2 packed unaligned dcl 1-7 set ref 90
error_table_$badopt                 000414 external static   fixed bin(35,0)   dcl 58 set ref 84
exec_com                            000416 constant          entry             external dcl 377 ref 391
failure_block_ptr               14         based             fixed bin(17,0)   array level 3 packed unaligned dcl 1-7 set ref 287
                                                                               303 307 316 318 329 333 335
fp                                  000102 automatic         pointer           dcl 50 set ref 146 150 155 160 165 170 175 180 185
                                                                               190 195 200 205 210 215 220 225 230 235 240 245
                                                                               250 287 287 287 289 303 305 309 311 311 318 321
                                                                               322 328 328 329
hcs_$initiate                       000304 constant          entry             external dcl 7 ref 274
hcs_$make_seg                       000316 constant          entry             external dcl 7 ref 89
i                                   000100 automatic         fixed bin(17,0)   dcl 50 set ref 117 118 284 285 285 285 285 287 395
                                                                               395 397 397
i                                          parameter         fixed bin(17,0)   unaligned dcl 299 ref 295 303 307 309 316 316 318
                                                                               322 326 329 333 335 336
i                                   000100 automatic         fixed bin(17,0)   dcl 346 set ref 358 359
impure_ptr                                 based             pointer           dcl 377 ref 383 386 386 387 391 391
info_ptr                                   parameter         pointer           dcl 346 ref 342
```

```
interval                                000276 internal static fixed bin(35,0);   dcl 50 set ref 72 81 266
ioa_                                    000330 constant        entry              external dcl 7 ref 278 279 281 282 283 285 290
ioa_$ioa_stream                         000326 constant        entry              external dcl 7 ref 257
label_var                               000206 automatic       label variable     dcl 377 set ref 382 383 386 386 387 391 391
last_failure_block             1(18)           based           fixed bin(17,0)    level 2 packed unaligned dcl 1-7 set ref 90 309
                                                                                  309 316 316 336 336
last_test_time                 16              based           fixed bin(71,0)    array level 3 dcl 1-7 set ref 118 142 143
lock_word                                      based           bit(36)            level 2 dcl 373 set ref 383 387
max_test                                003055 constant        fixed bin(17,0)    initial dcl 50 ref 100 264
mc_ptr                                         parameter       pointer            dcl 346 ref 342
n_conds                                 003054 constant        fixed bin(17,0)    initial dcl 346 ref 358
next_block                     4               based           fixed bin(17,0)    level 2 packed unaligned dcl 2-10 set ref 287 303
                                                                                  309 311 329 333
next_code                      0(18)           based           fixed bin(17,0)    level 2 packed unaligned dcl 1-7 set ref 102 127
                                                                                  127
number_of_attempts             12              based           fixed bin(17,0)    array level 3 dcl 1-7 set ref 120 138 285
number_of_failures             13              based           fixed bin(17,0)    array level 3 dcl 1-7 set ref 255 255 285
number_of_tests                10              based           fixed bin(17,0)    level 2 dcl 1-7 set ref 100 117 264
p                                       000100 automatic       pointer            dcl 299 set ref 302 303 305 329 329 329 331 333
ref_label                               000272 internal static label variable     dcl 50 set ref 135 364
seg_version                             003056 constant        fixed bin(17,0)    initial dcl 50 ref 321
setacl                                  000420 constant        entry              external dcl 377 ref 385 388
sp                                      000010 internal static pointer            dcl 50 set ref 89 90 90 90 100 101 102 106 108 115
                                                                                  117 118 118 127 127 127 128 137 138 138 138 138
                                                                                  140 140 140 141 142 142 142 142 142 142 143 143
                                                                                  144 255 255 255 255 257 264 264 264 265 285 274
                                                                                  275 279 279 281 284 285 285 285 287 287 287 303
                                                                                  303 303 307 309 309 311 316 316 316 318 318 329
                                                                                  329 329 333 333 335 336 336 361 362 391


subv$com                                000336 constant        entry              external dcl 7 ref 146
subv$cioc                               000346 constant        entry              external dcl 7 ref 170
subv$dis                                000350 constant        entry              external dcl 7 ref 175
subv$lacl                               000360 constant        entry              external dcl 7 ref 195
subv$lam                                000362 constant        entry              external dcl 7 ref 200
subv$ldbr                               000342 constant        entry              external dcl 7 ref 160
subv$ldt                                000340 constant        entry              external dcl 7 ref 180
subv$rcu                                000366 constant        entry              external dcl 7 ref 210
subv$rmcm                               000352 constant        entry              external dcl 7 ref 180
subv$sam                                000364 constant        entry              external dcl 7 ref 205
subv$scu                                000370 constant        entry              external dcl 7 ref 150
subv$sdbr                               000344 constant        entry              external dcl 7 ref 165
subv$smcm                               000354 constant        entry              external dcl 7 ref 185
subv$smic                               000356 constant        entry              external dcl 7 ref 190
subverter$timer                         000334 constant        entry              external dcl 7 ref 78 78 120 120 267 267
test_in_progress               2               based           fixed bin(17,0)    level 2 dcl 1-7 set ref 106 108 127 128 259 279
                                                                                  279 361
test_names                              000012 internal static char(32)           initial array unaligned dcl 50 set ref 100 257 279
                                                                                  285 391
time                                    000170 automatic       fixed bin(71,0)    dcl 50 set ref 139 140 141 142 143 266 267
time_of_failure                2               based           fixed bin(71,0)    level 2 dcl 2-10 set ref 289
time_of_last_test              4               based           fixed bin(71,0)    level 2 dcl 1-7 set ref 115 118 140 141
timer_manager_$alarm_call_inhibit
                                        000312 constant        entry              external dcl 7 ref 128 267
timer_manager_$reset_alarm_call
                                        000314 constant        entry              external dcl 7 ref 78
tp                                      000102 automatic       pointer            dcl 299 set ref 331 333
type                           1               based           fixed bin(17,0)    level 2 dcl 2-10 set ref 322 328
user_info_$homedir                      000320 constant        entry              external dcl 7 ref 88 273
version                                        based           fixed bin(17,0)    level 2 dcl 2-10 set ref 321 328
```

```
mc_ptr                                    parameter      pointer              dcl 346 ref 342
mcir                               000105 automatic      char(168)            unaligned dcl 50 set ref 88 89 273 274
word_zero                                 based          bit(36)              dcl 377 ref 386 391

NAMES DECLARED BY DECLARE STATEMENT AND NEVER REFERENCED.
failure_block                             based          structure            level 1 dcl 2-18
impure                                    based          structure            level 1 dcl 373
scu_data                      5           based          fixed bin(17,0)      array level 2 dcl 2-18
subvert_statistics                        based          structure            level 1 dcl 1-7
tests                        12           based          structure            array level 2 dcl 1-7

NAMES DECLARED BY EXPLICIT CONTEXT.
c                                  000000 constant       label                dcl 146 ref 144 146 150 155 160 165 170 175 180
                                                                              185 190 195 200 205 210 215 220 225 230 235 240
                                                                              243 250
check_zero                         002677 constant       entry                internal dcl 378 ref 134 262 378
display                            001634 constant       entry                external dcl 271 ref 271
dummy_label                        003046 constant       label                dcl 395 ref 382 395
fault_handler                      002611 constant       entry                internal dcl 342 ref 136 136 342
finish_setup                       001017 constant       label                dcl 119 ref 119 129
free_failure_block                 002446 constant       entry                internal dcl 326 ref 326 382
get_failure_block                  002237 constant       entry                internal dcl 295 ref 137 295
next_setup                         001565 constant       label                dcl 262 ref 139 262
no_seg                             000072 constant       label                dcl 92 ref 92 279
scream_bloody_murder               001515 constant       label                dcl 255 ref 148 152 157 162 167 172 177 182 187
                                                                              192 197 202 207 212 217 222 227 232 237 242 247
                                                                              252 255
subverter                          000432 constant       entry                external dcl 3 ref 3
subverter$reset                    001076 constant       entry                external dcl 125 ref 125
subverter$timer                    001121 constant       entry                external dcl 132 ref 132

NAMES DECLARED BY CONTEXT OR IMPLICATION.
addr                                                     builtin function     internal ref 383 386 386 387 391 391
null                                                     builtin function     internal ref 98 279
pointer                                                  builtin function     internal ref 287 287 383 383 311 318 329 329 333
                                                                              386 391
rel                                                      builtin function     internal ref 287 383 329 329

STORAGE REQUIREMENTS FOR THIS PROGRAM.

          Object      Text       Link       Symbol      Defs       Static
Start          0         0       3542         4164      3057         3952
Length      4540      3057        422          342       463          412

External procedure subverter uses 280 words of automatic storage
Internal procedure get_failure_block uses 74 words of automatic storage
Internal procedure fault_handler uses 76 words of automatic storage
Internal procedure check_zero shares stack frame of external procedure subverter

THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
cp_cs                  call_ext_out_desc    call_ext_out         call_int_this        call_int_other       return
set_cs                 tra_label_var        ext_entry            int_entry            int_entry_desc       rpd_loop_1_ip_bp
rpd_loop_2_ip_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
access_violations_$fetch       access_violations_$ld           access_violations_$illegal_bounds_fault
access_violations_$illegal_opcodes                              access_violations_$lgad_bounds_fault
access_violations_$store       access_violations_$xed_fetch    access_violations_$xed_store  clock_
com_err_                       cu_$arg_ptr                     cv_dec_check_                 date_time_
```

```
default_handler_$set            exec_com                        hcs_$initiate                   hcs_$make_seg
ioa_                            ioa_$ioa_stream                 setacl                          subv$com
subv$cloc                       subv$dis                        subv$lacl                       subv$lam
subv$ldbr                       subv$ldt                        subv$rcu                        subv$rmca
subv$sam                        subv$scu                        subv$sdbr                       subv$smca
subv$smic                       subverter$timer                 timer_manager_$alarm_call_inhibit
timer_manager_$reset_alarm_call                                 user_info_$homedir

THE FOLLOWING EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.
error_table_$badopt


  LINE    LOC    LINE    LOC    LINE    LOC    LINE    LOC    LINE    LOC    LINE    LOC    LINE    LOC
     3 000431      72 000437      73 000442      74 000460      76 000462      78 000476      79 000511
    81 000517      82 000543      84 000545      85 000605      88 000606      89 000617      90 000665
    92 000672      94 000731      96 000732      98 000734     100 000741     101 000743     102 000745
   103 000747     106 000750     108 000753     111 001016     115 001017     117 001027     118 001040
   119 001047     120 001051     122 001074     125 001075     127 001103     128 001116     129 001117
   132 001123     134 001126     135 001127     136 001133     137 001144     138 001153     139 001172
   140 001170     141 001176     142 001200     143 001222     144 001231     146 001235     148 001244
   150 001245     152 001254     155 001255     157 001264     160 001265     162 001274     165 001275
   167 001304     170 001305     172 001314     175 001315     177 001324     180 001325     182 001334
   185 001335     187 001344     190 001345     192 001354     195 001355     197 001364     200 001365
   202 001374     205 001375     207 001404     210 001405     212 001414     215 001415     217 001424
   220 001425     222 001434     225 001435     227 001444     230 001445     232 001454     235 001455
   237 001464     240 001465     242 001474     245 001475     247 001504     250 001505     252 001514
   255 001515     257 001524     260 001562     262 001565     264 001566     265 001600     266 001607
   267 001612     268 001632     271 001633     273 001641     274 001662     275 001724     278 001731
   279 001766     281 001775     282 002024     283 002042     284 002057     285 002070     287 002150
   289 002165     290 002202     291 002223     292 002233     293 002235     295 002236     300 002251
   305 002274     306 002276     307 002307     309 002326     311 002353     313 002360     316 002361
   318 002415     321 002433     322 002435     323 002444     326 002445     328 002460     329 002464
   331 002504     332 002515     333 002525     335 002556     336 002571     338 002607     342 002610
   350 002631     359 002640     361 002654     362 002657     364 002666     366 002671     367 002673
   368 002676     370 002677     382 002700     383 002703     385 002705     386 002744     387 002751
   388 002752     389 003011     391 003012     393 003045     395 003046     397 003047     398 003050
```

```
       COMPILATION LISTING OF SEGMENT access_violations_
       Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
       Compiled on: 04/10/74  1843.9 edt Wed
           Options: map

          1
          2  access_violations_:
          3      procedure;
          4          return;                                                 /* should never enter here */
  1       1 /* start of include file subvert_statistics.incl.pl1
  1       2
  1       3          Initially coded by 2 Lt. Paul Karger  19 July 1972 0900 */
  1       4
  1       5
  1       6          declare
  1       7
  1       8          1 subvert_statistics based(sp) aligned,
  1       9               2 cur_test fixed bin(17) unal,             /* number of current test in progress */
  1      10               2 next_code fixed bin(17) unal,            /* next opcode number */
  1      11               2 end_of_segment fixed bin(17) unal,                /* rel pointer to end of segment */
  1      12               2 last_failure_block fixed bin(17) unal,   /* rel pointer to last failure block used */
  1      13               2 test_in_progress fixed bin,              /* test number of test in progress
  1      14                                                             = 0 if no test in progress
  1      15                                                            identifies test in progress if machine crashes */
  1      16               2 time_of_last_test fixed bin(71),
  1      17               2 cum_total_time fixed bin(71),
  1      18               2 number_of_tests fixed bin,
  1      19               2 tests(i refer(number_of_tests)) aligned,
  1      20                    3 number_of_attempts fixed bin,       /* number of attempts of this test */
  1      21                    3 number_of_failures fixed bin,       /* number of machine or software failures found */
  1      22                    3 failure_block_ptr fixed bin(17) unal, /* rel pointer to start of threaded list of failure blocks */
  1      23                    3 last_test_time fixed bin(71),
  1      24                    3 cum_test_time fixed bin(71);
  1      25
  1      26 /* End of subvert_statistics.incl.pl1 */
          5
  2       1 /* Start of include file failure_block.incl.pl1
  2       2
  2       3          Initially coded by 2 Lt. Paul Karger    19 July 1972   0900 */
  2       4 /*       Modified 21 July 72 0820 by P. Karger to use fixed bin unal
  2       5
  2       6
  2       7                                                       */
  2       8
  2       9          declare
  2      10
  2      11          1 failure_block based(fp) aligned,
  2      12               2 version fixed bin,                           /* version number = 1 */
  2      13               2 type fixed bin,                              /* index of test in test array */
  2      14               2 time_of_failure fixed bin(71),
  2      15               2 next_block fixed bin(17) unal,
  2      16               2 scu_data(5) fixed bin;                       /* rel pointer to next failure block of this type */
  2      17                                                       /* to be defined */
  2      18
  2      19 /* End of include file failure_block.incl.pl1 */
          6
          7          declare
          8               high_code fixed bin int static init (104),
          9               hcs_$truncate_seg entry (ptr, fixed bin, fixed bin),
         10               scratch_p ptr int static init (null ()),
               codes (0:104) fixed bin int static init (0, 3, 6, 8, 10, 11, 12, 14, 15, 24, 25, 26, 28, 47, 56, 60,
                      72, 74, 75, 76, 88, 89, 90, 91, 92, 124, 136, 138, 139, 140, 152, 188, 204, 220, 252, 259,
                    260, 262, 263, 264, 266, 267, 268, 270, 271, 272, 274, 276, 278, 282, 284, 286, 298, 304, 306,
                    308, 309, 310, 311, 314, 315, 316, 318, 321, 322, 323, 324, 328, 329, 332, 334, 337, 338, 339,
                    340, 342, 344, 348, 350, 360, 365, 366, 369, 370, 371, 372, 374, 376, 378, 380, 382, 390, 393,
                    394, 409, 410, 420, 444, 457, 458, 459, 460, 472, 476, 504),
               bounds_fault_ok condition,
               get_pdir_ entry returns (char (168)),
               clock_ entry returns (fixed bin (71)),
               subv$legal_pf entry (ptr),
               subv$try_op entry (fixed bin, ptr),
               subv$illegal_bf entry (ptr, fixed bin (35)),
               subv$xed_fetcher entry (ptr, fixed bin (35)),
               subv$ld_inst entry (ptr),
               subv$xed_storer entry (ptr),
               hcs_$make_seg entry (char (*), char (*), char (*), fixed bin (5), ptr, fixed bin),
               com_err_ entry options (variable),
               hcs_$acl_add1 entry (char (*), char (*), char (*), fixed bin (5), dim (0:2) fixed bin (6), fixed
                    bin),
               cu_$level_get entry (fixed bin),
               no_acc_p ptr int static init (null ()),
               rewa_p ptr int static init (null ()),
               read_p ptr int static init (null ()),
               code fixed bin,
               fp ptr,
               sp pointer init (pointer (fp, 0)),
               array (0:262143) fixed bin (35) based,
               bitstring bit (2359295) aligned based,
               i fixed bin (35),
               j fixed bin,
               p ptr based,
               rings (0:2) fixed bin (6);






get_scratch_seg:
          proc;
               if scratch_p = null () then call hcs_$make_seg ("", "subverter_temp_3_", "", 01111b, scratch_p,
                    code);
               call hcs_$truncate_seg (scratch_p, 0, code);
          end;
get_rewa_seg:
          procedure;

               call hcs_$make_seg ("", "subverter_temp_4_", "", 01111b, rewa_p, code);
          end;



get_no_acc_seg:
          procedure;
               if no_acc_p = null () then call hcs_$make_seg ("", "subverter_temp_1_", "", 00100b, no_acc_p, code);
          end;

get_read_seg:
```

```
            procedure;
                 if read_p = null () then
                      do;
                           call hcs_$make_seg ("", "subverter_temp_2_", "", 01111b, read_p, code);
                           read_p -> p = pointer (read_p, 7); /* create pointer to word 7 */
                           substr (unspec (read_p -> p), 67, 6) = "101110"b;
                                                              /* put in id modifier to its pointer */
                           read_p -> array (7) = 100000000b;  /* fill in the tally in the indirect word */
                           call cu_$level_get (j);            /* get validation level */
                           rings (*) = j;
                           call hcs_$acl_add1 (get_pdir_ (), "subverter_temp_2_", "", 01000b, rings, code);
                                                              /* reset the acl */

                      end;
            end;


fetch:
     entry (fp);                                              /* attempts to read data from execute only procerure */
          call get_no_acc_seg;                                /* make sure we have a pointer to the segment */
          i = no_acc_p -> array (0);                          /* make the reference */
          time_of_failure = clock_ ();                        /* should never get here */
          scu_data (1) = i;                                   /* save whatever we got */
          return;


store:
     entry (fp);                                              /* attempt to write data into execute only segment */
          call get_no_acc_seg;
          no_acc_p -> array (0) = 17;                         /* try to store */
          time_of_failure = clock_ ();                        /* failed */
          return;


xed_fetch:
     entry (fp);                                              /* try to fetch with xed instruction */
          call get_no_acc_seg;
          call subv$xed_fetcher (no_acc_p, i);                /* go into alm code */
          time_of_failure = clock_ ();                        /* should not return */
          scu_data (1) = i;
          return;


xed_store:
     entry (fp);                                              /* try to store with an xed instruction */
          call get_no_acc_seg;
          call subv$xed_storer (no_acc_p);                    /* go into alm */
          time_of_failure = clock_ ();                        /* should not return */
          return;


id:
     entry (fp);                                              /* try to store using an indirect and tally modifier */
          call get_read_seg;                                  /* get a read only segment with data initialized */
          call subv$id_inst (read_p);                         /* go into alm code */
          time_of_failure = clock_ ();                        /* should never return */
          return;


legal_bounds_fault:
     entry (fp);
          call get_rewa_seg;
          call subv$legal_bf (rewa_p);
          if rewa_p -> bitstring = "0"b then signal condition (bounds_fault_ok);
          do i = 0 to 65535;
               if rewa_p -> array (i) ^= 0 then
                    do;
                         time_of_failure = clock_ ();
                         scu_data (1) = i;
                         scu_data (2) = rewa_p -> array (i);
                         return;
                    end;
          end;
          scu_data (1) = -1;                                         /* indicate found non-zero first time */
          scu_data (2) = 0;                                          /* but zero the second */
          return;


illegal_bounds_fault:
     entry (fp);
          call get_rewa_seg;
          call subv$illegal_bf (rewa_p, i);
          time_of_failure = clock_ ();
          scu_data (1) = i;
          return;

illegal_opcodes:
     entry (fp);
          call get_scratch_seg;
          if next_code = high_code then next_code = 0;
          else next_code = next_code + 1;
          call subv$try_op (codes (next_code), scratch_p);
          time_of_failure = clock_ ();
          scu_data (1) = codes (next_code);
          return;
     end;
```

```
        INCLUDE FILES USED IN THIS COMPILATION.

 LINE    NUMBER    NAME                                  PATHNAME
   5          1    subvert_statistics.incl.pl1           >user_dir_dir>Druid>Karger>compiler_pool>subvert_statistics.incl.pl1
   6          2    failure_block.incl.pl1                >user_dir_dir>Druid>Karger>compiler_pool>failure_block.incl.pl1
```

```
              NAMES DECLARED IN THIS COMPILATION.

 IDENTIFIER                OFFSET    LOC STORAGE CLASS   DATA TYPE                 ATTRIBUTES AND REFERENCES

 NAMES DECLARED BY DECLARE STATEMENT.
 array                                     based             fixed bin(35,0)       array dcl 8 set ref 89 98 134 138 77
 bitstring                                 based             bit(2359295)          dcl 8 ref 132
 bounds_fault_ok                    000100 stack reference   condition             dcl 8 ref 132
 clock_                             000210 constant          entry                 external dcl 8 ref 98 99 107 116 124 136 151 161
 code                               000106 automatic         fixed bin(17,0)       dcl 8 set ref 52 54 59 66 73 88
 codes                              000012 internal static   fixed bin(17,0)       initial array dcl 8 set ref 160 162
 cu_$level_get                      000232 constant          entry                 external dcl 8 ref 78
 fp                                        parameter         pointer               dcl 8 ref 86 90 91 95 99 103 107 108 112 116 120
                                                                                   124 128 136 137 138 142 143 147 151 152 159 161
                                                                                   162 8
 get_pdir_                          000206 constant          entry                 external dcl 8 ref 88 88
 hcs_$acl_add                       000230 const nt          entry                 external dcl 8 ref 88
 hcs_$make_seg                      000226 constant          entry                 external dcl 8 ref 52 59 66 73
 hcs_$truncate_seg                  000204 constany          entry                 external dcl 8 ref 54
 high_code                                 constant          fixed bin(17,0)       initicl dcl 8 ref 158
 i                                  000112 automatic         fixed bin(35,0)       dcl 8 set ref 89 91 106 108 133 134 137 138 150
                                                                                   152
 j                                  000113 automatic         fixed bin(17,0)       dcl 8 set ref 78 79
 next_code                 0(18)           based             fixed bin(17,0)       level 2 packed unaligned dcl 1-7 set ref 158 158
                                                                                   159 159 160 162
 no_acc_p                           000164 internal static   pointer               initial dcl 8 set ref 89 98 106 115 46 66
 p                                         based             pointer               dcl 8 set ref 74 75
 read_p                             000170 internal static   pointer               initial dcl 8 set ref 123 71 73 74 74 75 77
 rewa_p                             000166 internal static   pointer               initial dcl 8 set ref 131 132 134 138 150 99
 rings                              000114 automatic         fixed bin(6,0)        array dcl 8 set ref 79 88
 scratch_p                          000010 internal static   pointer               initial dcl 8 set ref 160 52 92 54
 scu_data                  5               based             fixed bin(17,0)       array level 2 dcl 2-10 set ref 91 100 137 138 142
                                                                                   143 152 162
 sp                                 000110 automatic         pointer               initial dcl 8 set ref 8 158 158 159 159 160 162
                                                                                   3
 subv$id_inst                       000222 constant          entry                 external dcl 8 ref 123
 subv$illegal_bf                    000216 constant          entry                 external dcl 8 ref 158
 subv$legal_bf                      000212 constant          entry                 external dcl 8 ref 131
 subv$try_op                        000214 constant          entry                 external dcl 8 ref 160
 subv$xed_fetcher                   000220 constant          entry                 external dcl 8 ref 106
 subv$xed_storer                    000224 constant          entry                 external dcl 8 ref 115
 time_of_failure           2               based             fixed bin(71,0)       level 2 dcl 2-10 set ref 98 99 107 116 124 136 151
                                                                                   161

 NAMES DECLARED BY DECLARE STATEMENT AND NEVER REFERENCED.
 coe_err_                           000000 constant          entry                 external dcl 8
 cum_test_time             20              based             fixed bin(71,0)       array level 3 dcl 1-7
 cum_total_time            6               based             fixed bin(71,0)       level 2 dcl 1-7
 cur_test                                  based             fixed bin(17,0)       level 2 packed unaligned dcl 1-7
 end_of_segment            1               based             fixed bin(17,0)       level 2 packed unaligned dcl 1-7
 failure_block                             based             st-ucture             level 1 dcl 2-10
 failure_block_ptr         14              based             fixed bin(17,0)       array level 3 packed unaligned dcl 1-7
 last_failure_block        1(18)           based             fixed bin(17,0)       level 2 packed unaligned dcl 1-7
 last_test_time            16              based             fixed bin(71,0)       array level 3 dcl 1-7
 next_block                4               based             fixed bin(17,0)       level 2 packed unaligned dcl 2-10
 number_of_attempts        12              based             fixed bin(17,0)       array level 3 dcl 1-7
 number_of_failures        13              based             fixed bin(17,0)       array level 3 dcl 1-7
 number_of_tests           10              based             fixed bin(17,0)       level 2 dcl 1-7
 subvert_statistics                        based             structure             level 1 dcl 1-7
 test_in_progress          2               based             fixed bin(17,0)       level 2 dcl 1-7
```

```
tests                         12              based              structure               array level 2 dcl 1-7
time_of_last_test              4              based              fixed bin(71,0)         level 2 dcl 1-7
type                           1              based              fixed bin(17,0)         level 2 dcl 2-10
version                                       based              fixed bin(17,0)         level 2 dcl 2-10

NAMES DECLARED BY EXPLICIT CONTEXT.
access_violations_                 000057 constant   entry                   external dcl 2 ref 2
fetch                              000067 constant   entry                   external dcl 86 ref 86
get_no_acc_seg                     000664 constant   entry                   internal dcl 64 ref 88 97 106 114 64
get_read_seg                       000735 constant   entry                   internal dcl 69 ref 122 69
get_rewa_seg                       000615 constant   entry                   internal dcl 56 ref 130 149 56
get_scratch_seg                    000530 constant   entry                   internal dcl 50 ref 157 50
id                                 000243 constant   entry                   external dcl 120 ref 120
illegal_bounds_fault               000400 constant   entry                   external dcl 147 ref 147
illegal_opcodes                    000441 constant   entry                   external dcl 155 ref 155
legal_bounds_fault                 000275 constant   entry                   external dcl 128 ref 128
store                              000122 constant   entry                   external dcl 95 ref 95
xed_fetch                          000150 constant   entry                   external dcl 103 ref 103
xed_store                          000211 constant   entry                   external dcl 112 ref 112

NAMES DECLARED BY CONTEXT OR IMPLICATION.
null                                                 builtin function        internal ref 52 66 71
pointer                                              builtin function        internal ref 0 74
substr                                               builtin function        internal ref 75
unspec                                               builtin function        internal ref 75

STORAGE REQUIREMENTS FOR THIS PROGRAM.

           Object      Text       Link       Symbol      Defs       Static
Start           0         0       1356         1612      1122         1366
Length       2106      1122        234          261       233          224

External procedure access_violations_ uses 296 words of automatic storage
Internal procedure get_scratch_seg shares stack frame of external procedure access_violations_
Internal procedure get_rewa_seg shares stack frame of external procedure access_violations_
Internal procedure get_no_acc_seg shares stack frame of external procedure access_violations_
Internal procedure get_read_seg shares stack frame of external procedure access_violations_

THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
cp_cs3a            call_ext_out_desc    call_ext_out         return              signal              ext_entry
rpd_loop_1_ip_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
clock_                        cu_$level_get                 get_pdir_                     hcs_$acl_add1
hcs_$make_seg                 hcs_$truncate_seg             subv$id_inst                  subv$illegal_bf
subv$legal_bf                 subv$try_op                   subv$xed_fetcher              subv$xed_storer

NO EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.


   LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC
      0 000047         2 000056         4 000065        86 000066        88 000075        89 000076        90 000101
     91 000113        92 000120        95 000121        97 000130        98 000131        99 000134       100 000146
    103 000147       105 000156       106 000157       107 000170       108 000202       109 000207       112 000210
    114 000217       115 000220       116 000227       117 000241       120 000242       122 000251       123 000252
    124 000261       125 000273       128 000274       130 000303       131 000304       132 000313       133 000323
    134 000327       136 000333       137 000345       138 000352       139 000360       141 000361       142 000366
```

```
143 000373    144 000376    147 000377    149 000406    150 000407    151 000428    152 000432
153 000437    155 000440    157 000447    158 000450    159 000461    160 000470    161 000504
162 000516    163 000527     50 000530     52 000531     54 000600     55 000614     56 000615
 59 000616     60 000663     64 000664     66 000665     67 000734     69 000735     71 000736
 73 000743     74 001010     75 001014     77 001017     78 001021     79 001027     80 001042
 83 001128
```

```
ASSEMBLY LISTING OF SEGMENT >user_dir_dir>Druid>Karger>compiler_pool>subv.alm
ASSEMBLED ON:       04/11/74  1826.1 edt Thu
OPTIONS USED:       list  old_object  old_call  symbols
ASSEMBLED BY:       ALM Version 4.4, September 1973
ASSEMBLER CREATED:  02/13/74  1728.8 edt Wed

   000000                          1             name      subv
   000000               000331     2             entry     try_op
   000000               000267     3             entry     legal_bf
   000000               000310     4             entry     illegal_bf
   000000               000212     5             entry     xed_fetcher
   000000               000224     6             entry     xed_storer
   000000               000240     7             entry     ld_inst
   000000               000000     8             entry     cam
   000000               000010     9             entry     scu
   000000               000020    10             entry     ldt
   000000               000030    11             entry     ldbr
   000000               000040    12             entry     sdbr
   000000               000050    13             entry     cioc
   000000               000060    14             entry     dis
   000000               000070    15             entry     rmcm
   000000               000100    16             entry     smcm
   000000               000110    17             entry     smic
   000000               000120    18             entry     lacl
   000000               000130    19             entry     lam
   000000               000140    20             entry     sam
   000000               000150    21             entry     rcu
   000000               000002    22             equ       time_of_failure,2
   000000               000003    23             equ       low_order_time,3
   000000               000005    24             equ       save_area,5        Place to save registers, etc.
                                  25             temp8     bases,registers
                                  26             tempd     control
                                  27
   000000  aa  6 00022 3521 20    28   cam:      save
   000001  aa  2 00020 6521 00
   000002  aa  2 00100 3521 00
   000003  aa  2 77722 2521 00
   000004  aa  2 77700 3331 00
   000005  aa  6 00032 2501 00
8  000006  aa    000000 5320 00   29             cam       0
   000007  aa    000151 7100 04   30             tra       master_mode_succeeded-*,ic Should never get here
                                  31
   000010  aa  6 00022 3521 20    32   scu:      save
   000011  aa  2 00020 6521 00
   000012  aa  2 00100 3521 00
   000013  aa  2 77722 2521 00
   000014  aa  2 77700 3331 00
   000015  aa  6 00032 2501 00
   000016  aa    000000 6570 00   33             scu       0
   000017  aa    000141 7100 04   34             tra       master_mode_succeeded-*,ic Should never get here either
                                  35
   000020  aa  6 00022 3521 20    36   ldt:      save
   000021  aa  2 00020 6521 00
   000022  aa  2 00100 3521 00
   000023  aa  2 77722 2521 00
   000024  aa  2 77700 3331 00
   000025  aa  6 00032 2501 00
   000026  aa    000000 6370 00   37             ldt       0
   000027  aa    000131 7100 04   38             tra       master_mode_succeeded-*,ic
                                  39
```

```
000030  aa  6 00022 3521 20     40   ldbr:      save
000031  aa  2 00020 6521 00
000032  aa  2 00100 3521 00
000033  aa  2 77722 2521 00
000034  aa  2 77700 3331 00
000035  aa  6 00032 2501 00
000036  aa   000000 2320 00     41              ldbr       0
000037  aa   000121 7100 04     42              tra        master_mode_succeeded-*,ic
                                43
                                44
000040  aa  6 00022 3521 20     45   sdbr:      save
000041  aa  2 00020 6521 00
000042  aa  2 00100 3521 00
000043  aa  2 77722 2521 00
000044  aa  2 77700 3331 00
000045  aa  6 00032 2501 00
000046  aa   000000 1540 00     46              sdbr       0
000047  aa   000111 7100 04     47              tra        master_mode_succeeded-*,ic
                                48
                                49
000050  aa  6 00022 3521 20     50   cioc:      save
000051  aa  2 00020 6521 00
000052  aa  2 00100 3521 00
000053  aa  2 77722 2521 00
000054  aa  2 77700 3331 00
000055  aa  6 00032 2501 00
000056  aa   000000 0150 00     51              cioc       0
000057  aa   000101 7100 04     52              tra        master_mode_succeeded-*,ic
                                53
                                54
000060  aa  6 00022 3521 20     55   dis:       save
000061  aa  2 00020 6521 00
000062  aa  2 00100 3521 00
000063  aa  2 77722 2521 00
000064  aa  2 77700 3331 00
000065  aa  6 00032 2501 00
000066  aa   000000 6160 00     56              dis        0
000067  aa   000071 7100 04     57              tra        master_mode_succeeded-*,ic
                                58
                                59
000070  aa  6 00022 3521 20     60   rmcm:      save
000071  aa  2 00020 6521 00
000072  aa  2 00100 3521 00
000073  aa  2 77722 2521 00
000074  aa  2 77700 3331 00
000075  aa  6 00032 2501 00
000076  aa   000000 2330 00     61              rmcm       0
000077  aa   000061 7100 04     62              tra        master_mode_succeeded-*,ic
                                63
                                64
000100  aa  6 00022 3521 20     65   smcm:      save
000101  aa  2 00020 6521 00
000102  aa  2 00100 3521 00
000103  aa  2 77722 2521 00
000104  aa  2 77700 3331 00
000105  aa  6 00032 2501 00
000106  aa   000000 5530 00     66              smcm       0
000107  aa   000051 7100 04     67              tra        master_mode_succeeded-*,ic
                                68
```

```
      000110  aa  6 00022 3521 20    69
                                     70  smlc:     save
      000111  aa  2 00020 6521 00
      000112  aa  2 00100 3521 00
      000113  aa  2 77722 2521 00
      000114  aa  2 77700 3331 00
      000115  aa  6 00032 2501 00
      000116  aa    000000 4510 00   71            smlc      0
      000117  aa    000041 7100 04   72            tra       master_mode_succeeded-*,ic
                                     73
                                     74
      000120  aa  6 00022 3521 20    75  lacl:     save
      000121  aa  2 00020 6521 00
      000122  aa  2 00100 3521 00
      000123  aa  2 77722 2521 00
      000124  aa  2 77700 3331 00
      000125  aa  6 00032 2501 00
8     000126  aa    000000 4530 00   76            lacl      0
      000127  aa    000031 7100 04   77            tra       master_mode_succeeded-*,ic
                                     78
                                     79
      000130  aa  6 00022 3521 20    80  lam:      save
      000131  aa  2 00020 6521 00
      000132  aa  2 00100 3521 00
      000133  aa  2 77722 2521 00
      000134  aa  2 77700 3331 00
      000135  aa  6 00032 2501 00
8     000136  aa    000000 2570 00   81            lam       0
      000137  aa    000021 7100 04   82            tra       master_mode_succeeded-*,ic
                                     83
                                     84
      000140  aa  6 00022 3521 20    85  sam:      save
      000141  aa  2 00020 6521 00
      000142  aa  2 00100 3521 00
      000143  aa  2 77722 2521 00
      000144  aa  2 77700 3331 00
      000145  aa  6 00032 2501 00
8     000146  aa    000000 5570 00   86            sam       0
      000147  aa    000011 7100 04   87            tra       master_mode_succeeded-*,ic
                                     88
                                     89
      000150  aa  6 00022 3521 20    90  rcu:      save
      000151  aa  2 00020 6521 00
      000152  aa  2 00100 3521 00
      000153  aa  2 77722 2521 00
      000154  aa  2 77700 3331 00
      000155  aa  6 00032 2501 00
      000156  aa    000000 6130 00   91            rcu       0
      000157  aa    000001 7100 04   92            tra       master_mode_succeeded-*,ic
                                     93
                                     94
                                     95
      000160                         96  master_mode_succeeded:
8     000160  aa  6 00050 2541 00    97            stb       bases
      000161  aa  6 00060 7531 00    98            sreg      registers
      000162  aa  6 00070 3571 00    99            stcd      control
                                    100
C     000163  aa  0 00002 3521 20   101            eapbp     ap|2,*           Get pointer to argument 1
C     000164  aa  2 00000 3521 20   102            eapbp     bp|0,*           Argument 1 is a pointer
```

```

  000165  4a  4 00202 6331 20                rcc1    <sys_info>|[clock_],*  Read the clock
  000166  aa  2 00002 7551 00                sta     bp|time_of_failure   Store high order bits
  000167  aa  2 00003 7561 00                stq     bp|low_order_time    Store low bits - can't use steq

  000170  aa   000000 6220 00                eax2    0                    Zero x2
  000171                          bases_loop:
  000171  aa  6 00050 2361 12                ldq     bases,2
  000172  aa  2 00005 7561 12                stq     bp|save_area,2
  000173  aa   000001 6220 12                eax2    1,2                  Increment by 1
  000174  aa   000010 1020 03                cmpx2   8,du                 < 8 ?
  000175  0a   000171 6040 00                tmi     bases_loop

  000176  aa   000000 6220 00                eax2    0
  000177                          regs_loop:
  000177  aa  6 00060 2361 12                ldq     registers,2
  000200  aa  2 00015 7561 12                stq     bp|save_area+8,2
  000201  aa  6 00020 1731 20                return
  000202  aa  6 00010 0731 00
  000203  aa  6 00024 6101 00
  000204  aa   000001 6220 12                eax2    1,2                  Increment loop counter by 1
  000205  aa   000010 1020 03                cmpx2   8,du                 < 8 ?
  000206  0a   000177 6040 00                tmi     regs_loop


  000207  aa  6 00070 2371 00                ldaq    control
  000210  aa  2 00025 7551 00                sta     bp|save_area+16
  000211  aa  2 00026 7561 00                stq     bp|save_area+17



  000212                          xed_fetcher:
  000212  aa  6 00022 3521 20                save
  000213  aa  2 00020 6521 00
  000214  aa  2 00100 3521 00
  000215  aa  2 77722 2521 00
  000216  aa  2 77700 3331 00
  000217  aa  6 00032 2501 00

C 000220  aa  0 00002 3521 20                eapbp   ap|2,*               get pointer to first arg
C 000221  aa  2 00000 3521 20                eapbp   bp|0,*               first arg is a ptr

  000222  0a   000261 7160 00                xec     xed_fetch            execute the xed instruction
  000223  0a   000254 7100 00                tra     fetch_succeeded


  000224                          xed_storer:
  000224  aa  6 00022 3521 20                save
  000225  aa  2 00020 6521 00
  000226  aa  2 00100 3521 00
  000227  aa  2 77722 2521 00
  000230  aa  2 77700 3331 00
  000231  aa  6 00032 2501 00
C 000232  aa  0 00002 3521 20                eapbp   ap|2,*
C 000233  aa  2 00000 3521 20                eapbp   bp|0,*

  000234  0a   000266 7160 00                xec     xed_store
  000235  aa  6 00020 1731 20                return
  000236  aa  6 00010 0731 00
```

```
    000237  aa  6 00024 6101 00
                                  149
                                  150
    000240  aa  6 00022 3521 20   151   id_inst:  save
    000241  aa  2 00020 6521 00
    000242  aa  2 00100 3521 00
    000243  aa  2 77722 2521 00
    000244  aa  2 77700 3331 00
    000245  aa  6 00032 2501 00
C   000246  aa  0 00002 3521 20   152             eppbp     ap|2,*
C   000247  aa  2 00000 3521 20   153             eppbp     bp|0,*
                                  154
    000250  aa  2 00000 2361 20   155             ldq       bp|0,*              its pointer at bp|0 with id modifier
    000251  aa  6 00020 1731 20   156             return
    000252  aa  6 00010 0731 00
    000253  aa  6 00024 6101 00
                                  157
    000254                        158   fetch_succeeded:
C   000254  aa  0 00004 3521 20   159             eppbp     ap|4,*              get pointer to second arg
    000255  aa  2 00000 7561 00   160             stq       bp|0                store result in it
    000256  aa  6 00020 1731 20   161             return
    000257  aa  6 00010 0731 00
    000260  aa  6 00024 6101 00
                                  162
    000261                        163   xed_fetch:
    000261  aa    000262 7170 00  164             xed       xed_fetch_pair
                                  165             even
    000262                        166   xed_fetch_pair:
    000262  aa  2 00000 2361 00   167             ldq       bp|0
    000263  aa    000000 0110 03  168             nop       0,du
                                  169
    000264                        170   xed_store_pair:
    000264  aa    000021 2360 07  171             ldq       17,dl
    000265  aa  2 00000 7561 00   172             stq       bp|0
                                  173
    000266                        174   xed_store:
    000266  aa    000264 7170 00  175             xed       xed_store_pair
                                  176
                                  177
                                  178
    000267  aa  6 00022 3521 20   179   legal_bf: save
    000270  aa  2 00020 6521 00
    000271  aa  2 00100 3521 00
    000272  aa  2 77722 2521 00
    000273  aa  2 77700 3331 00
    000274  aa  6 00032 2501 00
C   000275  aa  0 00002 3521 20   180             eppbp     ap|2,*              get pointer to arg 1
C   000276  aa  2 00000 3521 20   181             eppbp     bp|0,*              arg 1 is a pointer
    000277  aa    000000 6210 00  182             eax1      0                   put 0 in index register 1
    000300  aa    177777 6220 00  183             eax2      65535               to reference page 64
    000301  aa    000306 7170 00  184             xed       bounds_pair         do the bounds fault
    000302  aa  6 00020 1731 20   185             return
    000303  aa  6 00010 0731 00
    000304  aa  6 00024 6101 00
                                  186
    000305  aa    000000 0110 03  187             even
    000306                        188   bounds_pair:
    000306  aa  2 00000 2361 11   189             ldq       bp|0,1              reference first page
    000307  aa  2 00000 2361 12   190             ldq       bp|0,2              reference last page
```

```
                                            191
                                            192
    000310                                  193   illegal_bf:
    000310  aa  6 00022 3521 20             194             save
    000311  aa  2 00020 6521 00
    000312  aa  2 00100 3521 00
    000313  aa  2 77722 2521 00
    000314  aa  2 77700 3331 00
    000315  aa  6 00032 2501 00
C   000316  aa  0 00002 3521 20             195             eapbp     ap|2,*
C   000317  aa  2 00000 3521 20             196             eapbp     bp|0,*
    000320  aa    000000 6210 00            197             eax1      0
    000321  aa    303240 6220 00            198             eax2      100000         this time reference beyond 64K
    000322  aa    000306 7170 00            199             xed       bounds_pair    shuld fault
                                            200
C   000323  aa  0 00004 3521 20             201             eapbp     ap|4,*         get pointer to return point
    000324  aa  2 00000 7561 00             202             stq       bp|0           store the value we got illegally
    000325  aa  6 00020 1731 20             203             return
    000326  aa  6 00010 0731 00
    000327  aa  6 00024 6101 00
                                            204
    000330  aa    000000 0000 00            205   arg_0:    arg       0
    000331  aa  6 00022 3521 20             206   try_op:   save
    000332  aa  2 00020 6521 00
    000333  aa  2 00100 3521 00
    000334  aa  2 77722 2521 00
    000335  aa  2 77700 3331 00
    000336  aa  6 00032 2501 00
C   000337  aa  0 00002 3521 20             207             eapbp     ap|2,*
    000340  aa  2 00000 2361 00             208             ldq       bp|0           load the opcode
    000341  aa    000011 7360 00            209             qls       9              shift it left 9 bits
    000342  aa    000330 0760 00            210             adq       arg_0          add in the arg 0 instruction
C   000343  aa  0 00004 3521 20             211             eapbp     ap|4,*         pointer to arg 2
C   000344  aa  2 00000 3521 20             212             eapbp     bp|0,*         arg 2 is a pointer to segment
    000345  aa  2 00000 7561 00             213             stq       bp|0           store the instruction in the segment
    000346  aa  2 00000 7161 00             214             xec       bp|0           now execute the instruction
                                            215
    000347  aa  6 00020 1731 20             216             return
    000350  aa  6 00010 0731 00
    000351  aa  6 00024 6101 00
                                            217
                                            218
                                            219             end

NO LITERALS
```

NAME DEFINITIONS FOR ENTRY POINTS AND SEGDEFS

```
     000352  5a   000003 000000
     000353  2a   000174 000001
     000354  aa  003 162 143 165          rcu
     000355  5a   000006 000000
     000356  2a   000166 000001
     000357  aa  003 163 141 155          sam
     000360  5a   000011 000000
     000361  2a   000160 000001
     000362  aa  003 154 141 155          lam
     000363  5a   000015 000000
     000364  2a   000152 000001
     000365  aa  004 154 141 143          lacl
     000366  aa  154 000 000 000
     000367  5a   000021 000000
     000370  2a   000144 000001
     000371  aa  004 163 155 151          salc
     000372  aa  143 000 000 000
     000373  5a   000025 000000
     000374  2a   000136 000001
     000375  aa  004 163 155 143          sacm
     000376  aa  155 000 000 000
     000377  5a   000031 000000
     000400  2a   000130 000001
     000401  aa  004 162 155 143          racm
     000402  aa  155 000 000 000
     000403  5a   000034 000000
     000404  2a   000122 000001
     000405  aa  003 144 151 163          dis
     000406  5a   000040 000000
     000407  2a   000114 000001
     000410  aa  004 143 151 157          cloc
     000411  aa  143 000 000 000
     000412  5a   000044 000000
     000413  2a   000106 000001
     000414  aa  004 163 144 142          sdbr
     000415  aa  162 000 000 000
     000416  5a   000050 000000
     000417  2a   000100 000001
     000420  aa  004 154 144 142          ldbr
     000421  aa  162 000 000 000
     000422  5a   000053 000000
     000423  2a   000072 000001
     000424  aa  003 154 144 164          ldt
     000425  5a   000056 000000
     000426  2a   000064 000001
     000427  aa  003 163 143 165          scu
     000430  5a   000061 000000
     000431  2a   000056 000001
     000432  aa  003 143 141 155          cam
     000433  5a   000065 000000
     000434  2a   000050 000001
     000435  aa  007 151 144 137          id_inst
     000436  aa  151 156 163 164
     000437  5a   000072 000000
     000440  2a   000042 000001
     000441  aa  012 170 145 144          xed_storer
     000442  aa  137 163 164 157
     000443  aa  162 145 162 000
```

```
000444  50    000077 000000
000445  20    000034 000001
000446  00  013 170 145 144        xed_fetcher
000447  00  137 146 145 164
000450  00  143 150 145 162
000451  50    000104 000000
000452  20    000026 000001
000453  00  012 151 154 154        illegal_bf
000454  00  145 147 141 154
000455  00  137 142 146 000
000456  50    000111 000000
000457  20    000020 000001
000460  00  010 154 145 147        legal_bf
000461  00  141 154 137 142
000462  00  146 000 000 000
000463  56    000115 000000
000464  20    000012 000001
000465  00  006 164 162 171        try_op
000466  00  137 157 160 000
000467  50    000123 000000
000470  50    000000 000002
000471  00  014 163 171 155        symbol_table
000472  00  142 157 154 137
000473  00  164 141 142 154
000474  00  145 000 000 000
000475  50    000130 000000
000476  60    000037 000002
000477  00  010 162 145 154        rel_text
000500  00  137 164 145 170
000501  00  164 000 000 000
000502  50    000135 000000

000504  00  010 162 145 154        rel_link
000505  00  137 154 151 156
000506  00  153 000 000 000
000507  50    000142 000000

000511  00  012 162 145 154        rel_symbol
000512  00  137 163 171 155
000513  00  142 157 154 000
000514  00    000000 000000
```

EXTERNAL NAMES

```
000515  00  006 143 154 157        clock_
000516  00  143 153 137 000
000517  00  010 163 171 163        sys_info
000520  00  137 151 156 146
000521  00  157 000 000 000
```

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

```
000522  00    000004 000000
000523  55    000145 000143
000524  00    000001 000000
000525  00    000000 000000
```

LINKAGE INFORMATION

```
000000  ••     000000 000000
000001  ••     000352 000000
000002  ••     000000 000000
000003  ••     000000 000000
000004  ••     000000 000000
000005  ••     000000 000000
000006  22     000010 000204
000007  •2     000000 000204
000010  9•     777770 0000 46          "text!
000011  5•     000155 0000 17
000012  3•     777766 3700 04          (entry_sequence)
000013  L•     000003 0540 04
000014  0•     000331 6270 00
000015  L•     777773 7100 24
000016  ••     000000 000000
000017  ••     000000 000000
000020  3•     777760 3700 04          (entry_sequence)
000021  L•     000003 0540 04
000022  0•     000267 6270 00
000023  L•     777765 7100 24
000024  ••     000000 000000
000025  ••     000000 000000
000026  3•     777752 3700 04          (entry_sequence)
000027  _•     000003 0540 04
000030  0•     000310 6270 00
000031  L•     777757 7100 24
000032  ••     000000 000000
000033  ••     000000 000000
000034  3•     777744 3700 04          (entry_sequence)
000035  _•     000003 0540 04
000036  0•     000212 6270 00
000037  L•     777751 7100 24
000040  ••     000000 000000
000041  ••     000000 000000
000042  3•     777736 3700 04          (entry_sequence)
000043  _•     000003 0540 04
000044  0•     000224 6270 00
000045  L•     777743 7100 24
000046  ••     000000 000000
000047  ••     000000 000000
000050  3•     777730 3700 04          (entry_sequence)
000051  _•     000003 0540 04
000052  0•     000240 6270 00
000053  L•     777735 7100 24
000054  ••     000000 000000
000055  ••     000000 000000
000056  3•     777722 3700 04          (entry_sequence)
000057  _•     000003 0540 04
000060  0•     000000 6270 00
000061  _•     777727 7100 24
000062  ••     000000 000000
000063  ••     000000 000000
000064  3•     777714 3700 04          (entry_sequence)
050065  L•     000003 0540 04
000066  0•     000010 6270 00
000067  L•     777721 7100 24
000070  ••     000000 000000
500071  ••     000000 000000
```

```
000072  3a   777746 3700 04        (entry_sequence)
000073  La   000003 0540 04
000074  0a   000020 6270 00
000075  La   777713 7100 24
000076  aa   000000 000000
000077  aa   000000 000000
000100  3a   777700 3700 04        (entry_sequence;
000101  La   000003 0540 04
000102  0a   000030 6270 00
000103  La   777705 7100 24
000104  aa   000000 000000
000105  aa   000000 000000
000106  3a   777672 3700 04        (entry_sequence)
000107  La   000003 0540 04
000110  0a   000040 6270 00
000111  La   777677 7100 24
000112  aa   000000 000000
000113  aa   000000 000000
000114  3a   777664 3700 04        (entry_sequence)
000115  La   000003 0540 04
000116  0a   000050 6270 00
000117  La   777671 7100 24
000120  aa   000000 000000
000121  aa   000000 000000
000122  3a   777656 3700 04        (entry_sequence)
000123  La   000003 0540 04
000124  0a   000060 6270 00
000125  La   777663 7100 24
000126  aa   000000 000000
000127  aa   000000 000000
000130  3a   777650 3700 04        (entry_sequence)
000131  La   000003 0540 04
000132  0a   000070 6270 00
000133  La   777655 7100 24
000134  aa   000000 000000
000135  aa   000003 000000
000136  3a   777642 3700 04        (entry_sequence)
000137  La   000003 0540 04
000140  0a   000100 6270 00
000141  La   777647 7100 24
000142  aa   000000 000000
000143  aa   000000 000000
000144  3a   777634 3700 04        (entry_sequence)
000145  La   000003 0540 04
000146  0a   000110 6270 00
000147  La   777641 7100 24
000150  aa   000000 000000
000151  aa   000000 000000
000152  3a   777626 3700 04        (entry_sequence)
000153  La   000003 0540 04
000154  3a   000120 6270 00
000155  La   777633 7100 24
000156  aa   000000 000000
000157  aa   000000 000000
000160  3a   777620 3700 04        (entry_sequence)
000161  La   000003 0540 04
000162  0a   000130 6270 00
000163  La   777625 7100 24
000164  aa   000000 000000
```

```
000165  aa   000000 000000
000166  3a   777612 3700 04       (entry_sequence)
000167  La   000003 0540 04
000170  0a   000140 6270 00
000171  La   777617 7100 24
000172  aa   000000 000000
000173  aa   000000 000000
000174  3a   777604 3700 04       (entry_sequence)
000175  La   000003 0540 04
000176  0a   000150 6270 00
000177  La   777611 7100 24
000200  aa   000000 000000
000201  aa   030000 000000
000202  9a   777576 0000 46       sys_info$clock_
000203  5a   000154 0000 20
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
     000000   00    000000 001001
     000001   00    240000 000033
     000002   00    000000 001045
     000003   00    240000 000427
     000004   00    000000 101452
     000005   00    141711 067671
     000006   00    000000 101561
     000007   00    726122 210541
     000010   00    000000 000000
     000011   00    000000 000002
     000012   00    000000 000000
     000013   00    000530 000204
     000014   00    000000 001474
     000015   00    240000 000440
     000016   00    003141 154155
     000017   00    037101 114115
     000020   00    040126 145162
     000021   00    163151 157156
     000022   00    040064 056064
     000023   00    054040 123145
     000024   00    160164 145155
     000025   00    142145 162040
     000026   00    061071 067063
     000027   00    163165 142166
     000030   00    040040 040040
     000031   00    040040 040040
     000032   00    040040 040040
     000033   00    040040 040040
     000034   00    040040 040040
     000035   00    040040 040040
     000036   00    040040 040040
```

```
          MULTICS ASSEMBLY CROSS REFERENCE LISTING

Value     Symbol                  Source file   Line number

          *text                   subv!           2,   3,   4,   5,   6,   7,   8,   9,  10,  11,  12,  13,
                                                 14,  15,  16,  17,  18,  19,  20,  21.
   330    arg_0                   subv!         205, 210.
    50    bases                   subv!          25,  97, 110.
   171    bases_loop              subv!         109, 114.
   306    bounds_pair             subv!         184, 188, 199.
     0    cam                     subv!           8,  20.
    50    cloc                    subv!          13,  50.
          clock_                  subv!         104.
    70    control                 subv!          26,  99, 126.
    60    dis                     subv!          14,  55.
   254    fetch_succeeded         subv!         139, 158.
   240    id_inst                 subv!           7, 151.
   310    illegal_bf              subv!           4, 193.
   120    lscl                    subv!          18,  75.
   130    lam                     subv!          19,  80.
    30    ldbr                    subv!          11,  40.
    20    ldt                     subv!          10,  36.
   267    legal_bf                subv!           3, 179.
     3    low_order_time          subv!          23, 186.
   160    master_mode_succeeded   subv!          30,  34,  38,  42,  47,  52,  57,  62,  67,  72,  77,  82,
                                                 87,  92,  96.
   150    rcu                     subv!          21,  90.
    60    registers               subv!          25,  98, 118.
   177    regs_loop               subv!         117, 123.
    70    rmcm                    subv!          15,  60.
   140    sam                     subv!          20,  85.
     5    save_area               subv!          24, 111, 119, 127, 128.
    10    scu                     subv!           9,  32.
    40    sdbr                    subv!          12,  45.
   100    smcm                    subv!          16,  65.
   110    smic                    subv!          17,  70.
          sys_info                subv!         104.
     2    time_of_failure         subv!          22, 105.
   331    try_op                  subv!           2, 206.
   261    xed_fetch               subv!         138, 163.
   212    xed_fetcher             subv!           5, 132.
   262    xed_fetch_pair          subv!         164, 156.
   265    xed_store               subv!         147, 174.
   224    xed_storer              subv!           6, 142.
   264    xed_store_pair          subv!         170, 175.

FATAL ERRORS ENCOUNTERED
```

APPENDIX B

Unlocked Stack Base Listing

This appendix contains listings of the four modules which make up the code needed to exploit the Unlocked Stack Base Vulnerability described in Section 3.3.3. The first two procedures, di and dia, implement step one of the vulnerability - inserting code into emergency_shutdown.link (referred to in the listings as esd.link.) The last two procedures, fi and fia, implement step two of the vulnerability - actually using the inserted code to read or write any 36 bit quantity in the system. Figure 9 in the main text corresponds to di and dia. Figure 10 corresponds to fi and fia. As in Appendix A, obsolete 645 instructions are flagged by the assembler.

```
COMPILATION LISTING OF SEGMENT di
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1838.9 edt Wed
     Options: map

di:
     proc;

/* Procedure to place trapdoor in emergency_shutdown.link */
          declare
          ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
          sp ptr,
          code fixed bin,
          com_err_ entry options (variable),
          i fixed bin,
          fi entry (ptr, bit (36) aligned),
          dia entry (ptr, ptr),
          mvoffset fixed bin int static init (296),          /* offset within emergency_shutdown.link at which to patch */
          mvp ptr;
          call ring0_get_$segptr ("", "signaller", sp, code); /* get segment number of signaller */
          if code ^= 0 then
               do;
error:

               call com_err_ (code, "di");
               return;
          end;
          call ring0_get_$segptr ("", "emergency_shutdown.link", mvp, code); /* get segment number of emergency_shutdown.link
*/
          if code ^= 0 then go to error;

          call dia (sp, addrel (mvp, mvoffset));                /* call alm program to finish */
          do i = mvoffset to mvoffset+11, mvoffset+14 to mvoffset+23; /* zero out all but 2 instruction patch */
               call fi (addrel (mvp, i), "0"b);                  /* other words were filled from registers */
          end;
     end;
```

```
        NAMES DECLARED IN THIS COMPILATION.

IDENTIFIER              OFFSET     LOC STORAGE CLASS   DATA TYPE                ATTRIBUTES AND REFERENCES

NAMES DECLARED BY DECLARE STATEMENT.
code                           000102 automatic        fixed bin(17,0)          dcl 6 set ref 15 16 18 22 23
com_err_                       000014 constant         entry                    external dcl 6 ref 18
die                            000020 constant         entry                    external dcl 6 ref 25
fi                             000016 constant         entry                    external dcl 6 ref 27
i                              000103 automatic        fixed bin(17,0)          dcl 6 set ref 26 27 27
avoffset                              constant         fixed bin(17,0)          initial dcl 6 ref 25 25 26 26 26 26
avp                            000104 automatic        pointer                  dcl 6 set ref 22 25 25 27 27
ring0_get_$segptr              000012 constant         entry                    external dcl 6 ref 15 22
sp                             000100 automatic        pointer                  dcl 6 set ref 15 25

NAMES DECLARED BY EXPLICIT CONTEXT.
di                             000020 constant         entry                    external dcl 1 ref 1
error                          000061 constant         label                    dcl 18 ref 18 23

NAME DECLARED BY CONTEXT OR IMPLICATION.
addrel                                                 builtin function         internal ref 25 25 27 27

STORAGE REQUIREMENTS FOR THIS PROGRAM.

           Object     Text        Link       Symbol     Defs       Static
Start           0        0         270         312       220          300
Length        454      220          22         127        50           12

External procedure di uses 118 words of automatic storage

THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
call_ext_out_desc   call_ext_out        return             ext_entry                rpd_loop_1_lp_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
com_err_                     die                           fi                                 ring0_get_$segptr

NO EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.


   LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC
      1 000017          15 000025          16 000057          18 000061          20 000100          22 000101          23 000132
     25 000134          26 000150          27 000161          28 000200          29 000217
```

```
ASSEMBLY LISTING OF SEGMENT >user_dir_dir>Druid>Karger>compiler_pool>die.alm
ASSEMBLED ON:      04/11/74  1824.7 edt Thu
OPTIONS USED:      list  old_object  old_call  symbols
ASSEMBLED BY:      ALM Version 4.4, September 1973
ASSEMBLER CREATED: 02/13/74  1728.8 edt Wed

    000000                             1              name      die
    000000                 000000      2              entry     die
                                       3              tempd     return_pointer,do_it_ptr
    000000  aa  6 00022 3521 20        4    die:      push
    000001  aa  2 00020 6521 00
    000002  aa  2 00060 3521 00
    000003  aa  2 77742 2521 00
    000004  aa  2 77720 3331 00
    000005  aa  6 00032 2501 00
    000006  aa   000030 2370 00        5              ldaq      xed_inst               "instructions in AQ
C   000007  0a   000023 3520 00        6              eapbp     return_inst            "pointer to return point
C   000010  aa  6 00050 2521 00        7              stpbp     return_pointer
C   000011  aa  6 00036 3701 00        8              eaplp     return_pointer-10 "signaller does tra lp|10,*
C   000012  aa  0 00004 3521 20        9              eapbp     ap|4,*
C   000013  aa  2 00000 3521 20       10              eapbp     bp|0,*                 "pointer to esd.link
C   000014  aa  6 00052 2521 00       11              stpbp     do_it_ptr
C   000015  aa  0 00002 3521 20       12              eapbp     ap|2,*
C   000016  aa  2 00000 3501 20       13              eapap     bp|0,*                 "ptr to signaller
C   000017  aa  6 00030 3521 00       14              eapbp     sp|0                   "save stack ptr
C   000020  aa  6 00052 3721 20       15              eapsp     do_it_ptr,*            "ptr to esd.link into sp
    000021  aa   777777 6200 00       16              eax0      -1
    000022  aa  0 00000 7101 00       17              tra       ap|0                   "transfer to signaller
    000023                            18    return_inst:
C   000023  aa  2 00000 3721 00       19              eapsp     bp|0                   "restore stack ptr
    000024  aa  6 00020 1731 20       20              return
    000025  aa  6 00010 0731 00
    000026  aa  6 00024 6101 00
                                      21
    000027  aa   000000 0110 03       22              even
    000030                            23              inhibit   on                     "so trapdoor isn't interrupted
    000030  aa  2 00000 7173 00       24    xed_inst: xed       bp|0                   "here's the trapdoor!
    000031  aa  2 00002 7103 00       25              tra       bp|2                   "so trapdoor can return
    000032                            26              inhibit   off
                                      27
                                      28              end

NO LITERALS
```

```
NAME DEFINITIONS FOR ENTRY POINTS AND SEGDEFS

     000032  5a   000003 000000
     000033  2a   000012 000001
     000034  aa  003 144 151 141        dia
     000035  5a   000011 000000
     000036  6a   000000 000002
     000037  aa  014 163 171 155        symbol_table
     000040  aa  142 157 154 137
     000041  aa  164 141 142 154
     000042  aa  145 000 000 000
     000043  5a   000016 000000
     000044  6a   000037 000002
     000045  aa  010 162 145 154        rel_text
     000046  aa  137 164 145 170
     000047  aa  164 000 000 000
     000050  5a   000023 000000

     000052  aa  010 162 145 154        rel_link
     000053  aa  137 154 151 156
     000054  aa  153 000 000 000
     000055  3a   000030 000000

     000057  aa  012 162 145 154        rel_symbol
     000060  aa  137 163 171 155
     000061  aa  142 157 154 000
     000062  aa   000000 000000

NO EXTERNAL NAMES

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

     000063  aa   000001 000000
     000064  aa   050000 000000

INTERNAL EXPRESSION WORDS

     000065  3a   000031 000000
```

LINKAGE INFORMATION

```
    000000  ■■   000000 000000
    000001  0■   000032 000000
    000002  ■■   030000 000000
    000003  ■■   000000 000000
    000004  ■■   000000 000000
    000005  ■■   000400 000000
    000006  22   000010 000020
    000007  ■2   000000 000020
    000010  3■   777770 0000 46          *text|
    000011  5■   000033 0000 17
    000012  3■   777766 3700 04          (entry_sequence)
    000013  _■   000003 0540 04
    000014  0■   000000 6270 00
    000015  _■   777773 7100 24
    000016  ■■   000000 000000
    000017  ■■   000000 000000
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
000000  00   000000 001001
000001  00   240000 000033
000002  00   000000 001045
000003  00   240000 000427
000004  00   000000 101452
000005  00   141711 067671
000006  00   000000 101561
000007  00   717414 003357
000010  00   000000 000000
000011  00   000000 000002
000012  00   000000 000000
000013  00   000066 000020
000014  00   000000 001474
000015  00   240000 000440
000016  00   003141 154155
000017  00   037101 114115
000020  00   040126 145162
000021  00   163151 157156
000022  00   040064 056064
000023  00   054040 123145
000024  00   160164 145155
000025  00   142145 162040
000026  00   061071 067063
000027  00   144151 141040
000030  00   040040 040040
000031  00   040040 040040
000032  00   040040 040040
000033  00   040040 040040
000034  00   040040 040040
000035  00   040040 040040
000036  00   040040 040040
```

```
                    MULTICS ASSEMBLY CROSS REFERENCE LISTING

     Value          Symbol                    Source file    Line number

                    *text                     dia               2.
          0         dia                       dia               2,     4.
         52         do_it_ptr                 dia               3,    11,    15.
         23         return_inst               dia               6,    18.
         50         return_pointer            dia               3,     7,     8.
         30         xed_inst                  dia               5,    24.

NO FATAL ERRORS
```

```
COMPILATION LISTING OF SEGMENT fi
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1040.9 edt Wed
    Options: map

fi:
     proc (fixp, word);

/* Entry to store 36 bits */

            declare
            ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
            mvoffset fixed bin int static init (296),
            ( sp,
            mvp)
            ptr,
            code fixed bin,
            fixp ptr,                                          /* pointer to word to be read/written */
            word bit (36) aligned,
            fia entry (ptr, ptr, ptr, bit (36) aligned),
            com_err_ entry options (variable),
            fia$gia entry (ptr, ptr, ptr, bit (36) aligned),
            fix bit (1) aligned;
            fix = "1"b;
            go to common;


gi:
            entry (fixp, word);
                                                               /* Entry to read out 36 bits */
            fix = "0"b;

common:
            call ring0_get_$segptr ("", "signaller", sp, code); /* get segment number of signaller */
            if code ^= 0 then
                 do;
error:
                 call com_err_ (code, "fi");
                 return;
            end;
            call ring0_get_$segptr ("", "emergency_shutdown.link", mvp, code); /*  get segment number of emergency_shutdown.lin
*/
            if code ^= 0 then go to error;
            if fix then call fia (sp, addrel (mvp, mvoffset+12), fixp, word); /* calll aim program to finish */
            else call fia$gia (sp, addrel (mvp, mvoffset+12), fixp, word);
     end;
```

```
          NAMES DECLARED IN THIS COMPILATION.

IDENTIFIER               OFFSET     LOC STORAGE CLASS   DATA TYPE                ATTRIBUTES AND REFERENCES

NAMES DECLARED BY DECLARE STATEMENT.
code                               000104 automatic     fixed bin(17,0)          dcl 7 set ref 28 30 32 36 37
com_err_                           000016 constant      entry                    external dcl 7 ref 32
fla                                000014 constant      entry                    external dcl 7 ref 38
fla$gla                            000020 constant      entry                    external dcl 7 ref 39
fix                                000105 automatic     bit(1)                   dcl 7 set ref 19 26 33
fixp                                      parameter     pointer                  dcl 7 set ref 1 23 38 39
mvoffset                                  constant      fixed bin(17,0)          initial dcl 7 ref 38 38 39 39
mvp                                000102 automatic     pointer                  dcl 7 set ref 36 38 38 39 39
ring0_get_$segptr                  000012 constant      entry                    external dcl 7 ref 28 36
sp                                 000106 automatic     pointer                  dcl 7 set ref 28 38 39
word                                      parameter     bit(36)                  dcl 7 set ref 1 23 38 39

NAMES DECLARED BY EXPLICIT CONTEXT.
common                             000040 constant      label                    dcl 28 ref 28 28
error                              000076 constant      label                    dcl 32 ref 32 37
fl                                 000021 constant      entry                    external dcl 1 ref 1
gl                                 000032 constant      entry                    external dcl 23 ref 23

NAME DECLARED BY CONTEXT OR IMPLICATION.
addrel                                                  builtin function         internal ref 38 38 39 39

STORAGE REQUIREMENTS FOR THIS PROGRAM.

        Object     Text       Link       Symbol    Defs      Static
Start        0        0        304          326     224         314
Length     470      224         22          130      60          12

External procedure fl uses 114 words of automatic storage

THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
call_ext_out_desc   call_ext_out         return                 ext_entry

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
com_err_                        fla                             fla$gla                       ring0_get_$segptr

NO EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.


   LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC        LINE    LOC
      1 000020          19 000026          20 000030          23 000031          26 000037          28 000040          30 000074
     32 000076          34 000115          36 000116          37 000152          38 000154          39 000201          40 000223
```

```
ASSEMBLY LISTING OF SEGMENT >user_dir_dir>Druid>Karger>compiler_pool>fia.alm
ASSEMBLED ON:         04/11/74  1826.0 edt Thu
OPTIONS USED:         list  old_object  old_call  symbols
ASSEMBLED BY:         ALM Version 4.4, September 1973
ASSEMBLER CREATED:    02/13/74  1728.8 edt Wed

    000000                                  1              name      fia
    000000                     000000       2              entry     fia
    000000                     000031       3              entry     gia
                                            4
                                            5              tempd     tra_p,fixp,wordp
                                            6              temp      word
    000000  aa  6 00022 3521 20             7   fia:       push                          "entry to store 36 bits
    000001  aa  2 00020 6521 00
    000002  aa  2 00060 3521 00
    000003  aa  2 77742 2521 00
    000004  aa  2 77720 3331 00
    000005  aa  6 00032 2501 00
C   000006  aa  0 00010 3521 20             8              eapbp     ap|8,*
    000007  aa  2 00000 2361 00             9              ldq       bp|0
    000010  aa  6 00056 7561 00            10              stq       word                "36 bits to be stored
C   000011  aa  0 00006 3521 20            11              eapbp     ap|6,*
C   000012  aa  2 00000 3521 20            12              eapbp     bp|0,*
C   000013  aa  6 00052 2521 00            13              stpbp     fixp                "ptr to where to store
C   000014  aa  0 00004 3521 20            14              eapbp     ap|4,*
C   000015  aa  2 00000 3701 20            15              eaplp     bp|0,*
C   000016  aa  6 00050 6501 00            16              stplp     tra_p               "ptr to trapdoor in esd.link
C   000017  aa  6 00036 3701 00            17              eaplp     tra_p-10            "signaller does tra lp|10,*
C   000020  aa    000024 3520 00           18              eapbp     ldq_stq             "ptr to instructions to xed
C   000021  aa  0 00002 3501 20            19              eapap     ap|2,*              "ptr to signaller
    000022  aa    777777 6200 00           20              eax0      -1
    000023  aa  0 00000 7101 20            21              tra       ap|0,*              "transfer to signaller
                                           22
                                           23              even
    000024                                 24              inhibit   on                  "trapdoor xed's these
    000024  aa  6 00056 2363 00            25   ldq_stq:   ldq       word                "load 36 bits to patch
    000025  aa  6 00052 7563 20            26              stq       fixp,*              "store 36 bits thru ptr
    000026                                 27              inhibit   off                 "trapdoor does tra bp|2
    000026  aa  6 00020 1731 20            28              return                        "and returns here
    000027  aa  6 00010 0731 00
    000030  aa  6 00024 6101 00
                                           29
                                           30
    000031  aa  6 00022 3521 20            31   gia:       push                          "entry to read out 36 bits
    000032  aa  2 00020 6521 00
    000033  aa  2 00060 3521 00
    000034  aa  2 77742 2521 00
    000035  aa  2 77720 3331 00
    000036  aa  6 00032 2501 00
C   000037  aa  0 00010 3521 20            32              eapbp     ap|8,*
C   000040  aa  6 00054 2521 00            33              stpbp     wordp               "ptr to output argument
C   000041  aa  0 00006 3521 20            34              eapbp     ap|6,*
C   000042  aa  2 00000 3521 20            35              eapbp     bp|0,*
C   000043  aa  6 00052 2521 00            36              stpbp     fixp                "ptr to where to read
C   000044  aa  0 00004 3521 20            37              eapbp     ap|4,*
C   000045  aa  2 00000 3701 20            38              eaplp     bp|0,*
C   000046  aa  6 00050 6501 00            39              stplp     tra_p               "ptr to trapdoor in esd.link
C   000047  aa  6 00036 3701 00            40              eaplp     tra_p-10            "signaller does tra lp|10,*
C   000050  aa    000054 3520 00           41              eapbp     ldq_stq_in_arg      "ptr to instructions to xed
C   000051  aa  0 00002 3501 20            42              eapap     ap|2,*              "ptr to signaller
```

```
000052  aa    777777 6200 00     43                eax0      -1
000053  aa  0 00000 7101 20      44                tra       ap|0,*             "transfer to signaller
                                 45                even
000054                           46                inhibit   on
000054                           47   ldq_stq_in_arg:                          "trapdoor xed's these
000054  aa  6 00052 2363 20      48                ldq       fixp,*             "load thru ptr
000055  aa  6 00054 7563 20      49                stq       wordp,*            "store in output argument
000056                           50                inhibit   off                "trapdoor does tra bp|2
000056  aa  6 00020 1731 20      51                return                       "and returns here
000057  aa  6 00010 0731 00
000060  aa  6 00024 6101 00
                                 52                end

NO LITERALS
```

```
NAME DEFINITIONS FOR ENTRY POINTS AND SEGDEFS

     000062  5a    000003 000000
     000063  2a    000020 000001
     000064  aa   003 147 151 141          gia
     000065  5a    000006 000000
     000066  2a    000012 000001
     000067  aa   003 146 151 141          fia
     000070  5a    000014 000000
     000071  6a    000000 000002
     000072  aa   014 163 171 155          symbol_table
     000073  aa   142 157 154 137
     000074  aa   164 141 142 154
     000075  aa   145 000 000 000
     000076  5a    000021 000000
     000077  6a    000037 000002
     000100  aa   010 162 145 154          rel_text
     000101  aa   137 164 145 170
     000102  aa   164 000 000 000
     000103  5a    000026 000000

     000105  aa   010 162 145 154          rel_link
     000106  aa   137 154 151 156
     000107  aa   153 000 000 000
     000110  5a    000033 000000

     000112  aa   012 162 145 154          rel_symbol
     000113  aa   137 163 171 155
     000114  aa   142 157 154 000
     000115  aa    000001 000000

NO EXTERNAL NAMES

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

     000116  aa    000001 000000
     000117  aa    000000 000000

INTERNAL EXPRESSION WORDS

     000120  5a    000034 000000
     000121  aa    000000 000000
```

LINKAGE INFORMATION

```
    000000  00   000000 000000
    000001  00   000062 000000
    000002  00   000000 000000
    000003  00   000000 000000
    000004  00   000000 000000
    000005  00   000000 000000
    000006  22   000010 000025
    000007  02   000000 000026
    000010  30   777770 0000 46       *text|
    000011  50   000034 0000 17
    000012  30   777766 3700 34       (entry_sequence)
    000013  40   000023 0540 04
    000014  30   000000 6270 00
    000015  40   777773 7100 24
    000016  00   000030 000000
    000017  00   000000 000000
    000020  30   777760 3700 04       (entry_sequence)
    000021  40   000003 0540 04
    000022  00   000031 6270 00
    000023  40   777765 7100 24
    000024  00   000000 000000
    000025  00   000000 000000
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
     000000   00   000000 001001
     000001   00   240000 000033
     000002   00   000000 001045
     000003   00   240000 000427
     000004   00   000000 101452
     000005   00   141711 067671
     000006   00   000000 101561
     000007   00   720061 637647
     000010   00   000000 000000
     000011   00   000000 000002
     000012   00   000000 000000
     000013   00   000122 000026
     000014   00   000000 001474
     000015   00   240000 000440
     000016   00   003141 154155
     000017   00   037101 114115
     000020   00   040126 145162
     000021   00   163151 157156
     000022   00   040064 056064
     000023   00   054040 123145
     000024   00   160164 145155
     000025   00   142145 162040
     000026   00   061071 067063
     000027   00   146151 141040
     000030   00   040040 040040
     000031   00   040040 040040
     000032   00   040040 040040
     000033   00   040040 040040
     000034   00   040040 040040
     000035   00   040040 040040
     000036   00   040040 040040
```

```
                MULTICS ASSEMBLY CROSS REFERENCE LISTING

    Value       Symbol                  Source file   Line number

                *text                   fiat            2,     3.
        0       fia                     fiat            2,     7.
       52       fixp                    fiat            5,    13,    26,    36,    48.
       31       gia                     fiat            3,    31.
       24       ldq_stq                 fiat           18,    25.
       54       ldq_stq_in_arg          fiat           41,    47.
       50       tra_p                   fiat            5,    16,    17,    39,    40.
       56       word                    fiat            6,    10,    25.
       54       wordp                   fiat            5,    33,    49.

NO FATAL ERRORS
```

APPENDIX C

Trap door in check$device_name Listing

This appendix contains listings of the trap door inserted in check$device_name in Section 3.4.5.2 and the two modules needed to call the trap door. Check$device_name is actually one entry point in the procedure check$device_index. The patches are shown in the assembly language listing of the code produced by the PL/I compilation of check$device_index. Most of the patches were placed in the entry sequence to check$device_index, taking advantage of the fact that PL/I entry sequences contain the ASCII representation of the entry name for debugging purposes. Since the debugger cannot run in ring 0, this is essentially free patching space. Additional patches were placed at each return point from check$device_name, so that the trap door would be executed whenever check$device_name returned to its caller.

Zg is a PL/I procedure which calls the trap door to either read or write any 36-bit word accessible in ring 0. Zg uses zdata, an assembly language routine, to define a structure in the linkage section which contains machine instructions with which to communicate with the trap door.

The trap door algorithm is as follows:

1. Set the bp register to point to the argument rcode. Rcode has been bound to zdata$code in the procedure call from zg and must lie on an odd word boundary.

2. Compare the double word at bp|1 with the key string in the trap door to see if this is a legitimate user calling. If the keys do not match, then just return. If the keys do match, then we know who this is and must proceed.

3. Do an execute double (XED) on the two instruction at bp|3. This allows the caller to provide any instructions desired.

4. The two instructions provided by zdata at bp|3 and bp|5 are ldq bp|5 and stq bp|7. Bp|5 and bp|7 contain pointers to the locations from which to read and to which to write, respectively. These pointers are set in zg.

5. Finally, the trap door simply returns upon completion of the XED pair.

```
COMPILATION LISTING OF SEGMENT check
Compiled by: Multics PL/I Compiler, Version of 5 October 1972.
Compiled on: 02/23/76  1135.3 edt Thu


check$device_index: proc (devx, dp, cctp, rcode);

dcl  devx fixed bin (12),
   /* dp ptr, */
       cctp ptr,
       rcode fixed bin (17),
       cctno fixed bin (18);

            dcl code fixed bin(17);

            dcl ioam_check ext entry;

dcl  error_table_$gim_no_cat ext fixed bin,
     error_table_$dev_nt_assnd ext fixed bin,
     error_table_$gim_badarg ext fixed bin;



/* BEGIN INCLUDE ...... dct ...... */

/* Declaration for the Device Configuration Table */

dcl 1 dct_seg$ ext aligned,                                      /* device configuration table */
      2 ndev fixed bin (17),                                     /* number of devices */
      2 desc (300 /* dev_nam_max */ ),                           /* start of device description */
        3 dev_nam char (32),                                     /* device name */
        3 phys_nam char (32),                                    /* name of physical channel and GIOC */
        3 giocno fixed bin (3),                                  /* GIOC number of this device */
        3 phychn fixed bin (12),                                 /* LPW channel number of this device */
        3 direct_chan bit (1);                                   /* ON if direct channel */

/* END INCLUDE ...... dct ...... */




/* BEGIN INCLUDE ...... cat ...... */

          /* Channel Assignment Table for the GIOC Interface Module */


dcl 1 cat_seg$ ext aligned,

     2 event fixed bin,                                          /* GIM wait event */

     2 abs_base fixed bin (24),                                  /* absolute address of base of DCW segment */

     2 stat_base bit (3),                                        /* status channel used by GIM */

     2 safep ptr,                                                /* pointer to safety DCW pair */

     2 devtab (200),                                             /* per-device-index information accessed */
                                                                 /* by the "devx" presented in the GIM calls */
      (3 cctno bit (18),                                         /* segment number of the CCT for this user */
                                                                 /* - only accessed by one process */
        3 dcv_rel_add bit (18),                /* offset of dcv list within dcv segment, */
                                               /* Zero is interpreted as dcv-list not */
                                               /* yet allocated */
        3 dcv_list_len bit (12),               /* size of dcv list in dcv's */
                                               /* */
        3 stat_x bit (10),                     /* index pointing to oldest item in status queue */
                                               /* */
        3 end_x bit (10),                      /* index pointing to end of status queue */
                                               /* */
        3 pad bit (1),                         /* */
                                               /* */
        3 status_lost bit (1),                 /* ON if status lost */
                                               /* */
        3 dir_chan bit (1),                    /* on if direct channel */
                                               /* */
        3 pad1 bit (1)) unaligned,             /* guess again */

      2 free_x fixed bin (10),                 /* index pointing to head of free status queue */

      2 overflow fixed bin (18),               /* status queue overflow count */

      2 stat_q (512) fixed bin (71);           /* status queue */
                                               /* remember to change cur_length of cat_seg in      */
                                               /* hardware header if you change this               */


dcl  dp ptr;                                   /* pointer to devtab entry */

dcl 1 dev_entry based (dp) aligned,            /* "devtab" entry declaration */
     (2 cstus bit (18);
      2 dev_rel_add bit (18),
      2 dev_list_len bit (12),
      2 stat_x bit (10),
      2 end_x bit (10);
      2 pad bit (1),
      2 status_lost bit (1),
      2 dir_chan bit (1)) unaligned;

/* END INCLUDE ...... cat ...... */




                        /*
```

```
*/


            rcode = 0;
            dp = addr(cat_seg$.devtab (devx));
            call ioam_check(devx,code);   /* see if device assigned to this process  */
            if code ^= 1 then do;                          /* it is not, so report error  */
              rcode = error_table_$dev_nt_assnd;
              cctp = null;
              return;
            end;
            cctno = dp -> dev_entry.cctno;
            if cctno = 0 then do;
                 rcode = error_table_$gim_no_cct;
                 cctp = null;
                 return;
            end;
            cctp = baseptr (cctno);
            return;


device_name: entry (devnam, dctx, rcode);

dcl  devnam char (*),                                        /* device name */
     dctx fixed bin (17);                                    /* device index from DCT */

/* setup and search the DCT for match */

            rcode = 0;
            do dctx = 1 to dct_seg$.ndev;
                 if dct_seg$.desc (dctx).dev_nam = devnam then return;
            end;

/* no matches, set complaint */

            rcode = error_table_$gim_badarg;
            return;


        end;
        VARIABLES DECLARED IN THIS COMPILATION.

    IDENTIFIER                LOC STORAGE CLASS        DATA TYPE                         ATTRIBUTES AND REFERENCES

    VARIABLES DECLARED BY DECLARE STATEMENT.
    abs_base                      external static      fixed bin(24,0)                   level 2 aligned dcl 78
    cat_seg                000040 external static      structure                         level 1 aligned dcl 78
    cctno                  000142 automatic            fixed bin(18,0)                   dcl 8 ref 111 112 117
    cctno                         external static      bit(18)                           array level 3 unaligned dcl 78
    cctno                         based                bit(18)                           level 2 unaligned dcl 93 ref 111
    cctp                          parameter            pointer                           dcl 8 ref 108 110 117
    code                   000143 automatic            fixed bin(17,0)                   dcl 10 ref 105 106
    dct_seg                000036 external static      structure                         level 1 aligned dcl 31
    dctx                          parameter            fixed bin(17,0)                   dcl 125 ref 130 131 132
    dcw_list_len                  external static      bit(12)                           array level 3 unaligned dcl 78
    dcw_list_len                  based                bit(12)                           level 2 unaligned dcl 93
    dcw_rel_add                   based                bit(18)                           level 2 unaligned dcl 93
    dcw_rel_add                   external static      bit(18)                           array level 3 unaligned dcl 78
    desg                   000036 external static      structure                         array level 2 aligned dcl 31
    dev_entry                     based                structure                         level 1 aligned dcl 93
    dev_nam                000036 external static      char(32)                          array level 3 aligned dcl 31 ref 131
    devnam                        parameter            char                              unaligned dcl 125 ref 131
    devtab                 000040 external static      structure                         array level 2 aligned dcl 78 ref 108
    devx                          parameter            fixed bin(12,0)                   dcl 8 ref 108 105
    dir_chan                      external static      bit(1)                            array level 3 unaligned dcl 78
    dir_chan                      based                bit(1)                            level 2 unaligned dcl 93
    direct_chan                   external static      bit(1)                            array level 3 aligned dcl 31
    dp                            parameter            pointer                           dcl 83 ref 109 111
    end_x                         based                bit(10)                           level 2 unaligned dcl 93
    end_x                         external static      bit(10)                           array level 3 unaligned dcl 78
    error_table_$dev_nt_assnd
                           000032 external static      fixed bin(17,0)                   dcl 16 ref 107
    error_table_$gim_badarg
                           000034 external stati'      fixed bin(17,0)                   dcl 16 ref 136
    error_table_$gim_no_ecs
                           000030 external static      fixed bin(17,0)                   dcl 16 ref 113
    event                         external static      fixed bin(17,0)                   level 2 aligned dcl 78
    free_x                        external static      fixed bin(10,0)                   level 2 aligned dcl 78
    gioqno                        external static      fixed bin(3,0)                    array level 3 aligned dcl 31
    ioam_check             000026 link reference       entry                             external irreducible ref 108
    ndev                   000036 external static      fixed bin(17,0)                   level 2 aligned dcl 31 ref 130
    overflow                      external static      fixed bin(18,0)                   level 2 aligned dcl 78
    pad                           external static      bit(1)                            array level 3 unaligned dcl 78
    pad                           based                bit(1)                            level 2 unaligned dcl 93
    padj                          external static      bit(1)                            array level 3 unaligned dcl 78
    phychn                        external static      fixed bin(12,0)                   array level 3 aligned dcl 31
    phys_nam                      external static      char(32)                          array level 3 aligned dcl 31
    rcode                         parameter            fixed bin(17,0)                   dcl 8 ref 103 107 113 129 136
    safep                         external static      pointer                           level 2 aligned dcl 78
    stat_base                     external static      bit(3)                            level 2 aligned dcl 78
    stat_q                        external static      fixed bin(71,0)                   array level 2 aligned dcl 78
    stat_x                        external static      bit(10)                           array level 3 unaligned dcl 78
    stat_x                        based                bit(10)                           level 2 unaligned dcl 93
    status_lost                   external static      bit(1)                            array level 3 unaligned dcl 78
    status_lost                   based                bit(1)                            level 2 unaligned dcl 93

    VARIABLES DECLARED BY EXPLICIT CONTEXT.
    check$device_index     000022 link reference       entry                             external irreducible ref 2
    device_name            000016 link reference       entry                             external irreducible ref 122
```

```
VARIABLES DECLARED BY CONTEXT OR IMPLICATION.
addr                                               built-in function               internal ref 104
baseptr                                            built-in function               internal ref 117
null                                               built-in function               internal ref 108 114
```

```
DESCRIPTOR IMAGES
000000  aa     000012000016

000001  aa     000012000021

CONSTANTS
000002  aa     000000000000   FIXED

000003  aa     000000000001   FIXED

000004  aa     000000000023   FIXED

000005  aa     000000000110   FIXED

000006  aa     000000000002   FIXED

000007  aa     777777777670   FIXED

000010  aa     777777000043   FIXED
000011  ra     000001000-00

SHORT PROCEDURE check$device_index
ENTRY TO check$device_index
000012  aa   143 150 145 143   chec
000013  aa   153 044 144 145   k$de
000014  aa   166 151 143 145   vice
000015  aa   137 151 156 144   _ind
000016  aa   145 170 000 000   ex
000017  aa      000000000022
000020  aa      000000000000
000021  aa      000000000000
000022  aa    000160 6270 00   eax7      112
000023  aa    000114 6260 00   eax6      76
000024  aa  4 00042 2721 20    tspbp     lp|34,*
000025  aa      760000000012
000026  aa  6 00122 2371 00    ldaq      sp|82
000027  aa  6 00146 7571 00    staq      sp|102
000030  aa    000002 2360 07   ldq       2,dl
000031  aa  6 00150 7561 00    stq       sp|104

000032  aa  6 00146 4501 20    stz       sp|102,*

000033  aa  6 00114 2361 20    ldq       sp|76,*
000034  aa    000001 7360 00   qls       1
000035  aa    000000 6220 06   eax2      0,ql
000036  aa  6 00044 3701 20    epplp     sp|36,*
000037  aa  4 00040 3521 72    eapbp     lp|32,*2
000040  aa  2 00004 3521 00    eapbp     bp|4
000041  aa  6 00156 2521 00    stpbp     sp|110
000042  aa  6 00156 2371 00    ldaq      sp|110
000043  aa  6 00116 7571 20    staq      sp|78,*

000044  aa  6 00114 3521 20    eapbp     sp|76,*
000045  aa  6 00102 2521 00    stpbp     sp|66
000046  aa  6 00143 3521 00    eapbp     sp|99
000047  aa  6 00104 2521 00    stpbp     sp|68
000050  aa    777730 3520 04   eapbp     -40,ic
000051  aa  6 00106 2521 00    stpbp     sp|70
000052  aa    777727 3520 04   eapbp     -41,ic
000053  aa  6 00110 2521 00    stpbp     sp|72
```

```
                                     PATCHES
STATEMENT 1 ON LINE 2
                          000012  eapbp   sp|102,*
                          000013  ldaq    bp|1
                          000014  cmpaq   4,ic         000020
                          000015  tze     ap|409       return
                          000016  xed     bp|3
                          000017  tra     ap|409       return
                          000020  oct     742331276057
                          000021  oct     421553170267

STATEMENT 1 ON LINE 103

STATEMENT 1 ON LINE 104

STATEMENT 1 ON LINE 105

000000 = 000012000016

000001 = 000012000021
```

```
000054  aa  6 00026 3521 20   eapbp     lp|22,*
000055  aa   010000 4310 07   fld       4096,dl
000056  aa  0 00622 6701 00   tsplp     ap|402                call_ext_out
                                                              STATEMENT 1 OF LINE 106
000057  aa  6 00143 2361 00   ldq       sp|99
000060  aa   000001 1160 07   cmpq      1,dl
000061  aa   000007 6000 04   tze       7,ic                  000070
                                                              STATEMENT 1 OF LINE 107
000062  aa  6 00044 3701 20   epplp     sp|36,*
000063  aa  6 00032 2361 20   ldq       lp|26,*
000064  aa  6 00146 7561 20   stq       sp|102,*
                                                              STATEMENT 1 OF LINE 108
000065  aa   777723 2370 04   ldaq      -45,ic                000010 = 777777000043
000066  aa  6 00120 7571 20   staq      sp|80,*
                                                              STATEMENT 1 OF LINE 109
000067  aa  0 00631 7101 00   tra       ap|409                return
                                                              STATEMENT 1 OF LINE 111
000070  aa  6 00116 3521 20   eapbp     sp|78,*
000071  aa  2 00000 2351 20   lda       bp|0,*
000072  aa   000066 7730 00   lrl       54
000073  aa  6 00142 7561 00   stq       sp|98
                                                              STATEMENT 1 OF LINE 112
000074  aa   000007 6010 04   tnz       7,ic                  000103
                                                              STATEMENT 1 OF LINE 113
000075  aa  6 00044 3701 20   epplp     sp|36,*
000076  aa  6 00030 2361 20   ldq       lp|24,*
000077  aa  6 00146 7561 20   stq       sp|102,*
                                                              STATEMENT 1 OF LINE 114
000100  aa   777710 2370 04   ldaq      -56,ic                000010 = 777777000043
000101  aa  6 00120 7571 20   staq      sp|80,*
                                                              STATEMENT 1 OF LINE 115
000102  aa  0 00631 7101 00   tra       ap|409                return
                                                              STATEMENT 1 OF LINE 117
000103  aa  6 00142 2361 00   ldq       sp|98
000104  aa   000000 3130 06   eabbb     0,ql
000105  aa  2 00000 3531 00   eapbb     bp|0
000106  aa  3 00000 3521 00   eapbp     bb|0
000107  aa  6 00154 2521 00   stpbp     sp|108
000110  aa  6 00154 2371 00   ldaq      sp|108
000111  aa  6 00120 7571 20   staq      sp|80,*
                                                              STATEMENT 1 OF LINE 118
000112  aa  0 00631 7101 00   tra       ap|409                return
                                                              STATEMENT 1 OF LINE 122
ENTRY TO device_name
000113  aa  144 145 166 151   devi
000114  aa  143 145 137 156   ce_n
000115  aa  141 155 145 000   ame
000116  aa      000000000013
000117  aa      600000000000
000120  aa      000000000000
000121  aa   000160 6270 00   eax7      112
000122  aa   000114 6260 00   eax6      76
000123  aa  4 00044 2721 20   tspbp     lp|36,*
000124  aa      760000000010
000125  aa  6 00120 2371 00   ldaq      sp|80
000126  aa  6 00146 7571 00   staq      sp|102
000127  aa   000001 2360 07   ldq       1,dl
000130  aa  6 00150 7561 00   stq       sp|104
000131  aa  6 00124 2361 20   ldq       sp|84,*
000132  aa   777777 3760 07   anq       262143,dl
```

```
000133  aa   6 00144 7561 00    stq       sp|100
000134  aa   6 00146 4501 20    stz       sp|102,*                   STATEMENT 1 ON LINE 129
000135  aa   6 00044 3701 20    eaplp     sp|36,*                    STATEMENT 1 ON LINE 130
000136  aa   4 00036 2361 20    ldq       lp|30,*
000137  aa   6 00152 7561 00    stq       sp|106
000140  aa     000001 2360 07   ldq       1,dl
000141  aa   6 00116 7561 20    stq       sp|78,*
000142  aa   6 00116 2361 20    ldq       sp|78,*
000143  aa   6 00152 1161 00    cmpq      sp|106
000144  aa     000002 6000 04   tze       2,ic                       000146
000145  aa     000024 6050 04   tpl       20,ic                      000171
000146  aa   6 00114 2371 00    ldaq      sp|76                      STATEMENT 1 ON LINE 134
000147  aa     000011 7320 00   qrs       9
000150  aa     000777 3760 07   anq       511,dl
000151  aa     000000 6270 06   eax7      0,ql
000152  aa   6 00116 2361 20    ldq       sp|78,*
000153  aa     000023 4020 07   mpy       19,dl
000154  aa     000000 6220 06   eax2      0,ql
000155  aa     000040 7260 07   lxl6      32,dl
000156  aa   6 00044 3701 20    eaplp     sp|36,*
000157  aa   4 00036 3521 72    eapbp     lp|30,*2
000160  aa   2 77756 3521 00    eapbp     bp|-18
000161  aa   0 00643 6701 00    tsblp     ap|419                     set_cma
000162  aa   6 00144 7261 00    lxl6      sp|100
000163  aa   6 00114 3521 20    eapbp     sp|76,*                    cp_ca
000164  aa   0 00610 6701 00    tsblp     ap|392                     000167
000165  aa     000002 6010 04   tnz       2,ic                       return          000166  tra    6,ic      000174
000166  aa   0 00631 7101 00    tra       ap|409                     STATEMENT 1 ON LINE 132
000167  aa   6 00116 0541 20    aos       sp|78,*                    000142
000170  aa     777752 7100 04   tra       -22,ic                     STATEMENT 1 ON LINE 136
000171  aa   6 00044 3701 20    eaplp     sp|36,*
000172  aa   4 00034 2361 20    ldq       lp|28,*
000173  aa   6 00146 7561 20    stq       sp|102,*
000174  aa   0 00631 7101 00    tra       ap|409                     STATEMENT 1 ON LINE 137
                                                                     return          000174  tra    -114,ic   000012
000175  aa   0 00631 7101 00    tra       ap|409                     STATEMENT 1 ON LINE 140
   END PROCEDURE check$device_index                                  return
```

```
COMPILATION LISTING OF SEGMENT zg
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1843.4 edt Wed
     Options: map

zg:   proc (dp, word);                                        /* Entry to read out 36 bits */
dcl  1 zdata$code ext static aligned,                         /* structure passed to ring 0 */
       2 code fixed bin aligned,                              /* standard system error code */
       2 key bit (72) aligned,                                /* 72 bit key to prevent accidental use */
       2 inst (2) bit (36) aligned,                           /* 2 instructions to be XED'ed by ring 0 */
       2 (ptr1, ptr2) ptr aligned;                            /* ptr to read 36 bits; ptr to store 36  bits */

dcl   dp ptr, word bit (36) aligned;
dcl   hcs_$check_device entry (char (*), fixed bin (17), fixed bin),
      dctx fixed bin (17) init (0);

           ptr1 = dp;
           ptr2 = addr (word);
common:    call hcs_$check_device ("", dctx, code);           /* call ring 0 */
           return;

zf:        entry (dp, word);                                  /* Entry to patch 36 bits */
           ptr1 = addr (word);
           ptr2 = dp;
           go to common;
      end;
```

```
          NAMES DECLARED IN THIS COMPILATION.

IDENTIFIER              OFFSET     LOC STORAGE CLASS   DATA TYPE             ATTRIBUTES AND REFERENCES

NAMES DECLARED BY DECLARE STATEMENT.
code                            000012 external static fixed bin(17,0)       level 2 dcl 2 set ref 14
dctx                            000100 automatic       fixed bin(17,0)       initial dcl 9 set ref 9 14 9
dp                                     parameter       pointer               dcl 8 ref 1 12 17 19
hcs_$check_device               000014 constant        entry                 external dcl 9 ref 14
inst                        3   000012 external static bit(36)               array level 2 dcl 2
qey                         1   000012 external static bit(72)               level 2 dcl 2
ptr1                        6   000012 external static pointer               level 2 dcl 2 set ref 12 18
ptr2                       10   000012 external static pointer               level 2 dcl 2 set ref 13 19
word                                   parameter       bit(36)               dcl 8 set ref 1 13 17 18
zdata$code                      000012 external static structure             level 1 dcl 2

NAMES DECLARED BY EXPLICIT CONTEXT.
common                          000030 constant        label                 dcl 14 ref 14 20
zf                              000052 constant        entry                 external dcl 17 ref 17
zg                              000011 constant        entry                 external dcl 1 ref 1

NAME DECLARED BY CONTEXT OR IMPLICATION.
addr                                                   builtin function      internal ref 13 18

STORAGE REQUIREMENTS FOR THIS PROGRAM.

          Object      Text       Link      Symbol     Defs       Static
Start          0         0        144         162       72          154
Length       322        72         16         126       52            6

External procedure zg uses 82 words of automatic storage

THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
call_ext_out_desc   return               ext_entry

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
hcs_$check_device

THE FOLLOWING EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.
zdata$code


   LINE    LOC       LINE    LOC       LINE    LOC       LINE    LOC       LINE    LOC       LINE    LOC       LINE    LOC
      9 000005          1 000010         12 000017         13 000025         14 000030         15 000050         17 000051
     18 000050         19 000065         20 000071
```

```
ASSEMBLY LISTING OF SEGMENT >user_dir_dir>Druid>Karger>compiler_pool>zdata.alm
ASSEMBLED ON:        04/11/74  1826.1 edt Thu
OPTIONS USED:        list  old_object  old_call  symbols
ASSEMBLED BY:        ALM Version 4.4, September 1973
ASSEMBLER CREATED:   02/13/74  1728.8 edt Wed

    000000                                    1                  name      zdata
    000000                    000011          2                  segdef    code          "make code addressable
                                              3                  use       impure
                                              4                  even                    "instructions below must be even
    000010  aa    000000 000000               5                  oct       0             "so pad here with 0
    000011  aa    000000 000000               6        code:     oct       0             "system error code
    000012  aa    742331 274457               7        key:      oct       742331274457  "72 bit key to compare in ring
    000013  aa    621553 174267               8                  oct       621553174267  "zero for accidental invocation
    000014  aa  2 00005 2361 20               9                  ldq       pp15,*        "load thru ptr1
    000015  aa  2 00007 7561 20              10                  stq       pp17,*        "store thru ptr2
    000016  aa    077777 000043              11                  its       -1,1          "ptr1
    000017  aa    000001 000000
    000020  aa    077777 000043              12                  its       -1,1          "ptr2
    000021  aa    000001 000000
                                             13                  join      /link/impure  "put in linkage section
                                             14                  end
NO LITERALS
```

```
NAME DEFINITIONS FOR ENTRY POINTS AND SEGDEFS

     000000  50    000004 000000
     000001  20    000011 000001
     000002  00  004 143 157 144           code
     000003  00  145 000 000 000
     000004  30    000012 000000
     000005  60    000000 000002
     000006  00  014 163 171 155           symbol_table
     000007  00  142 157 154 137
     000010  00  164 141 142 154
     000011  00  145 000 000 000
     000012  50    000017 000400
     000013  60    000037 000002
     000014  00  010 162 145 154           rel_text
     000015  00  137 164 145 170
     000016  00  164 000 000 000
     000017  50    000024 000000

     000021  00  010 162 145 154           rel_link
     000022  00  137 154 151 156
     000023  00  153 000 000 000
     000024  50    000031 000000

     000026  00  012 162 145 154           rel_symbol
     000027  00  137 163 171 155
     000030  00  142 157 154 000
     000031  00    000030 000000

NO EXTERNAL NAMES

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

     000032  00    000001 000000
     000033  00    000000 000000

INTERNAL EXPRESSION WORDS
```

```
LINKAGE  INFORMATION

     000000   00    000000 000000
     000001   00    000000 000000
     000002   00    000000 000000
     000003   00    000000 000000
     000004   00    000000 000000
     000005   00    000000 000000
     000006   22    000022 000022
     000007   02    000000 000022
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
     000000   **    000000 001001
     000001   **    240000 000033
     000002   **    000000 001045
     000003   **    240000 000427
     000004   **    000000 101457
     000005   **    141711 067671
     000006   **    000000 101561
     000007   **    720102 715324
     000010   **    000000 000000
     000011   **    400000 000002
     000012   **    000000 000000
     000013   **    000034 000022
     000014   **    000000 001474
     000015   **    240000 000440
     000016   **    003141 154155
     000017   **    037101 114115
     000020   **    040126 145162
     000021   **    163151 157156
     000022   **    040064 056064
     000023   **    054040 123145
     000024   **    160164 145155
     000025   **    142145 162040
     000026   **    061071 067063
     000027   **    172144 141164
     000030   **    141040 040040
     000031   **    040040 040040
     000032   **    040040 040040
     000033   **    040040 040040
     000034   **    040040 040040
     000035   **    040040 040040
     000036   **    040040 040040
```

```
                MULTICS ASSEMBLY CROSS REFERENCE LISTING

   Value        Symbol                   Source file   Line number

         11     code                     zdata1           2,    6.
         10     impure                   zdata1           3,   13.
         12     key                      zdata1           7.

NO FATAL ERRORS
```

APPENDIX D

Dump Utility Listing

This appendix is a listing of a dump utility program designed to use the trap door shown in Section 3.4.5 and Appendix C. The program, zd, is a modified version of the installed Multics command, ring_zero_dump, documented in the MPM Systems Programmers' Supplement <SPS73>. Zd will dump any segment whose SDW in ring zero is not equal to zero. In addition, zd will not dump the ring zero descriptor segment, because the algoritnm used would result in the ring 4 descriptor segment being completely replaced by the ring 0 descriptor segment which could potentially crash the system. Zd will also not dump master procedures, since modifying their SDW's could also crash the system.

```
COMPILATION LISTING OF SEGMENT zd
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1042.6 edt Wed
     Options: map

zd:    proc;

/* This procedure prints out specified locations of a segment
   in octal format. It checks first to see if the segment has a counterpart
   in ring 0 and if not checks the given name */

dcl   targ char (tc) based (tp),
     (error_table_$noarg, error_table_$segknown) fixed bin ext,
     (code, outl, i, tc, first, initsw, the_same, next_arg, offset, left, pg_size, bound) fixed bin,
      count fixed bin (35),
      f (3) char (16) aligned static init ("^6o  ^w", "^6o  ^w  ^w", "^6o  ^w  ^w  ^w"),
      data (1024) fixed bin,
      bdata (1024) bit (36) aligned based (addr (data)),
      overlay (0:left-1) bit (36) aligned based,
     (tp, datap, segptr) ptr,
      dirname char (168),
      ename char (32),
      cv_oct_check_ entry (char (*), fixed bin) returns (fixed bin (35)),
     (com_err_, ioa_) entry options (variable),
      ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
      hcs_$terminate_noname entry (ptr, fixed bin),
      hcs_$initiate entry (char (*), char (*), char (*), fixed bin, fixed bin, ptr, fixed bin),
     (zg$zf, zg) entry (ptr, bit (36) aligned),
      sw fixed bin,
      dseg_word bit (36) aligned based (addr (dseg)),
      cu_$arg_ptr ext entry (fixed bin, ptr, fixed bin, fixed bin),
      condition_ ext entry,
      expand_path_ ext entry (ptr, fixed bin, ptr, ptr, fixed bin);

dcl 1 dseg aligned,
     2 pad1 bit (19) unal,
     2 bnd bit (8) unal,
     2 size bit (1) unal,
     2 pad2 bit (2) unal,
     2 acc bit (6) unal;

dcl   save_acc bit(36) aligned,
      wdsegptr ptr;

          initsw = 0;                                       /* initsw = 0 if we haven't initiated a segment */
          datap = addr (data);                              /* get pointer to data area */

          call cu_$arg_ptr (1, tp, tc, code);               /* pick up the first arg (name/number) */
          if code = error_table_$noarg | tc = 0 then do;
               call ioa_ ("rzd segno/name first count");
               return;
          end;


          if targ = "-nm" | targ = "-name" then do;         /* user specified a segment number */
               next_arg = 3;                                /* next argument to pick up is # 3 */
               call cu_$arg_ptr (next_arg-1, tp, tc, code); /* pick up the ascii for the segment name */
               if code ^= 0 then do;                        /* not there */
missing:            call com_err_ (code, "rzd");            /* tell user he gave bad args */
                    return;
```

```
                end;
                go to get_name;
            end;

            next_arg = 2;                                      /* "first word" is at arg position 2 */
            i = cv_oct_check_ (targ, code);                    /* check for an octal number */
            if code ^= 0 then do;                              /* must have been a name (not an octal number ) */
get_name:       segptr = null ();                              /* initialize pointer to null(), says don't have it yet */
                call ring0_get_$segptr ("", targ, segptr, code); /* get pointer to the segment */
                if segptr = null () then do;                   /* segment is not a ring 0 segment */
                     call expand_path_ (tp, tc, addr (dirname), addr (ename), code); /* convert to dir/entry names */
                     if code ^= 0 then go to missing;          /* error in path name */
                     call hcs_$initiate (dirname, ename, "", 0, 0, segptr, code); /* get pointer to segment */
                     if code ^= 0 then if code ^= error_table_$segknown then go to missing;
                     initsw = 1;                               /* must terminate the segment later */
                end;
            end;
            else segptr = baseptr (i);                         /* get pointer to base of segment */


            if baseno(segptr) = "0"b                           /* You may not dump dseg this way */
                     then do;
                               call com_err_(0, "zd", "It is a no-no to dump dseg.");
                               return;
                     end;
            call cu_$arg_ptr (next_arg, tp, tc, code);         /* pick up second arg (first word to dump ) */
            if code = error_table_$noarg | tc = 0 then do;
                first = 0;
                count = 1000000;
                go to get_bound;
            end;
            first = cv_oct_check_ (targ, code);
            if code ^= 0 then do;                              /* bad specification for first word */
                call ioa_ ("^RBad first word ^a^B", targ);
                return;
            end;

            call cu_$arg_ptr (next_arg+1, tp, tc, code);       /* get count of words to dump */
            if code = error_table_$noarg | tc = 0 then count = 1; else do;
                count = cv_oct_check_ (targ, code);            /* convert count value */
                if code ^= 0 then do;                          /* bad value */
bad_count:           call ioa_ ("^RBad count value ^a^B", targ);
                     return;
                end;
            end;

get_bound:
            call ring0_get_$segptr("", "dseg", dsegptr, code);
            call zg (ptr (baseptr (0), baseno (segptr)), dseg_word); /* get size of segment from bound in SDW */
            if dseg_word = "0"b then do;
                call ioa_ ("SDW = 0");
                return;
            end;

                if substr (dseg.acc, 4, 3) = "100"b then do;
                     call ioa_ ("d:  Master procedure.  SDW = ^w", dseg_word);
                     return;
                end;
                dseg.acc = "110010"b;
                call zg(ptr(wdsegptr, baseno(segptr)), save_acc); /* get wired ring access and save in save_acc */
                call zg$zf(ptr(wdsegptr, baseno(segptr)), dseg_word);           /* change wired ring access to ring 0 access */
                if dseg.size then pg_size = 64; else pg_size = 1024; /* get page size */
                bound = (fixed (dseg.bnd, 8) + 1)*pg_size;          /* get words of segment */

                if count > bound - first then count = bound - first; else if count < 1 then go to bad_count;

                offset = 0;                                         /* specifies which 1024 word block we're moving from ring 0 */
                outi = 1;
loop:
                if count >= 1024 then left = 1024; else left = count; /* get number of words to print in this loop */
                addr (bdata) -> overlay = ptr (segptr, first+offset) -> overlay;
                i = 1;
                the_same = 0;                                       /* init suppression flag */
                if left <= 3 then go to rem;                        /* if <= 3 to print, do it straight out */
                do while (left > 3);                                /* loop in print loop while at least 4 words to print */
                    if the_same = 0 then
                    call ioa_ ("^6o  ^w  ^w  ^w  ^w", first+outi-1, data (i), data (i+1), data (i+2), data (i+3));
                    else if the_same = 1 then call ioa_ ("======");
                    do tc = 0 to 3;                                 /* check for duplicate line */
                        if data (i+tc) ^= data (i+tc+4) then go to different;
                    end;
                    the_same = the_same + 1;
                    go to skip;
different:          the_same = 0;
skip:
                    i = i + 4;
                    outi = outi + 4;
                    left = left - 4;
                end;

                offset = offset + 1024;
                count = count - 1024;
                if count > 0 then go to loop;                       /* loop back if still more to print */

                if left > 0 then do;                                /* get remaining words */
                    do tc = 0 to left-1;
                        if data (i+tc) ^= data (i+tc-4) then go to rem;
                    end;
                    if the_same < 2 then call ioa_ ("======");
                    go to check_init;
rem:
                    call ioa_ (f (left), first+outi-1, data (i), data (i+1), data (i+2));
                end;
check_init:
                call zg$zf(ptr(wdsegptr, baseno(segptr)), save_acc);        /* replace old wired ring access */
                if initsw ^= 0 then call hcs_$terminate_noname (segptr, code);
                return;

        end;
```

```
          NAMES DECLARED IN THIS COMPILATION.

 IDENTIFIER               OFFSET    LOC STORAGE CLASS   DATA TYPE           ATTRIBUTES AND REFERENCES

 NAMES DECLARED BY DECLARE STATEMENT.
 acc                      0(30) 002206 automatic        bit(6)              level 2 packed unaligned dcl 30 set ref 110 114
 bdata                                 based            bit(36)             array dcl 7 set ref 126
 bnd                      0(19) 002206 automatic        bit(8)              level 2 packed unaligned dcl 30 set ref 110
 bound                         000113 automatic        fixed bin(17,0)     dcl 7 set ref 110 120 120
 code                          000100 automatic        fixed bin(17,0)     dcl 7 set ref 43 44 52 53 54 61 62 64 66 67 68 69
                                                                            69 81 82 87 88 93 94 95 96 102 161
 com_err_                      000034 constant         entry               external dcl 7 ref 54 78
 count                         000114 automatic        fixed bin(35,0)     dcl 7 set ref 84 94 95 120 120 120 124 125 147 147
                                                                            148
 cu_$arg_ptr                   000052 constant         entry               external dcl 7 ref 43 52 81 93
 cv_oct_check_                 000032 constant         entry               external dcl 7 ref 61 87 95
 data                          000115 automatic        fixed bin(17,0)     array dcl 7 set ref 41 126 131 131 131 131 135 135
                                                                            152 152 156 156 156
 datap                         002120 automatic        pointer             dcl 7 set ref 41
 dirname                       002124 automatic        char(168)           unaligned dcl 7 set ref 66 66 68
 dseg                          002206 automatic        structure           level 1 packed dcl 30 set ref 104 105 111 116
 dseg_word                            based            bit(36)             dcl 7 set ref 104 105 111 116
 ename                         002176 automatic        char(32)            unaligned dcl 7 set ref 66 66 68
 error_table_$noarg            000026 external static  fixed bin(17,0)     dcl 7 ref 44 82 94
 error_table_$segknown         000030 external static  fixed bin(17,0)     dcl 7 ref 69
 expand_path_                  000054 constant         entry               external dcl 7 ref 66
 f                             000010 internal static  char(16)            initial array dcl 7 set ref 156
 first                         000104 automatic        fixed bin(17,0)     dcl 7 set ref 83 87 120 120 126 131 156
 hcs_$initiate                 000044 constant         entry               external dcl 7 ref 68
 hcs_$terminate_noname         000042 constant         entry               external dcl 7 ref 161
 i                             000102 automatic        fixed bin(17,0)     dcl 7 set ref 61 73 127 131 131 131 131 135 135
                                                                            142 148 152 152 156 156 156
 initsw                        000105 automatic        fixed bin(17,0)     dcl 7 set ref 40 78 161
 ioa_                          000036 constant         entry               external dcl 7 ref 45 89 97 106 111 131 133 154
                                                                            156
 left                          000111 automatic        fixed bin(17,0)     dcl 7 set ref 124 125 126 126 129 130 143 143 150
                                                                            151 156
 next_arg                      000107 automatic        fixed bin(17,0)     dcl 7 set ref 51 52 60 81 93
 offset                        000110 automatic        fixed bin(17,0)     dcl 7 set ref 122 126 146 146
 outi                          000101 automatic        fixed bin(17,0)     dcl 7 set ref 123 131 142 142 156
 overlay                              based            bit(36)             array dcl 7 set ref 126 126
 pad1                          002206 automatic        bit(19)             level 2 packed unaligned dcl 30
 pad2                     0(28) 002206 automatic        bit(2)              level 2 packed unaligned dcl 30
 pg_size                       000112 automatic        fixed bin(17,0)     dcl 7 set ref 117 117 118
 ring0_get_$segptr             000040 constant         entry               external dcl 7 ref 64 102
 save_acc                      002207 automatic        bit(36)             dcl 37 set ref 115 159
 segptr                        002122 automatic        pointer             dcl 7 set ref 63 64 65 68 73 76 104 104 115 115
                                                                            116 116 126 159 159 161
 size                     0(27) 002206 automatic        bit(1)              level 2 packed unaligned dcl 30 set ref 117
 targ                                  based            char                unaligned dcl 7 set ref 50 50 61 64 87 89 95 97
 tc                            000103 automatic        fixed bin(17,0)     dcl 7 set ref 43 44 50 50 52 61 61 64 64 66 81 82
                                                                            87 87 89 89 93 94 95 95 97 97 134 135 135 151 152
                                                                            152
 the_same                      000106 automatic        fixed bin(17,0)     dcl 7 set ref 120 131 133 137 137 139 154
 tp                            002116 automatic        pointer             dcl 7 set ref 43 50 50 52 61 64 66 81 87 89 92 95
                                                                            97
 wdsegptr                      002210 automatic        pointer             dcl 37 set ref 102 115 115 116 116 159 159
 zg                            000050 constant         entry               external dcl 7 ref 104 115
```

```
zg0zf                        000046 constant     entry                   external dcl 7 ref 116 159

NAMES DECLARED BY DECLARE STATEMENT AND NEVER REFERENCED.
condition_                   000000 constant     entry                   external dcl 7
sw                                  automatic    fixed bin(17,0)         dcl 7

NAMES DECLARED BY EXPLICIT CONTEXT.
bad_count                    000736 constant     label                   dcl 97 ref 97 120
check_init                   001463 constant     label                   dcl 159 ref 155 159
different                    001341 constant     label                   dcl 139 ref 135 139
get_bound                    000770 constant     label                   dcl 102 ref 85 102
get_name                     000327 constant     label                   dcl 63 ref 57 63
loop                         001175 constant     label                   dcl 124 ref 124 140
missing                      000250 constant     label                   dcl 54 ref 54 67 69
rem                          001424 constant     label                   dcl 156 ref 129 152 156
skip                         001342 constant     label                   dcl 140 ref 138 140
zd                           000114 constant     entry                   external dcl 1 ref 1

NAMES DECLARED BY CONTEXT OR IMPLICATION.
addr                                             builtin function        internal ref 41 66 66 66 66 104 105 111 116 126
                                                                         126
baseno                                           builtin function        internal ref 76 104 104 115 115 116 116 159 159
baseptr                                          builtin function        internal ref 73 104 104
fixed                                            builtin function        internal ref 118
null                                             builtin function        internal ref 63 65
ptr                                              builtin function        internal ref 104 104 115 115 116 116 126 159 159
substr                                           builtin function        internal ref 118

STORAGE REQUIREMENTS FOR THIS PROGRAM.

          Object    Text      Link      Symbol    Defs      Static
Start          0       0      1656        1734    1516        1666
Length      2124    1516        56         156     143          46

External procedure zd uses 1254 words of automatic storage

THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
r_e_as             cp_cs              call_ext_out_desc   call_ext_out       return             set_cs8
copy_words         ext_entry          rpd_loop_1_ip_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
com_err_                    cu_$arg_ptr                    cv_oct_check_                 expand_path_
hcs_$initiate               hcs_$terminate_noname          ioa_                          ring0_get_$segptr
zg                          zg0zf

THE FOLLOWING EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.
error_table_$noarg          error_table_$segknown


    LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC
       1 000113        40 000121        41 000122        43 000124        44 000143        45 000154        46 000171
      50 000172        51 000225        52 000227        53 000246        54 000250        55 000267        57 000270
      60 000271        61 000273        62 000325        63 000327        64 000331        65 000366        66 000372
      67 000415        68 000417        69 000460        70 000465        72 000467        73 000470        75 000474
      78 000477        79 000527        80 000530        82 000545        83 000556        84 000557        85 000561
      87 000552        88 000614        89 000616        90 000647        93 000650        94 000670        95 000704
      96 000734        97 000736        98 000767       102 000770       104 001017       105 001040       106 001042
```

```
107 001055   110 001056   111 001062   112 001103   114 001104   115 001106   116 001124
117 001142   117 001150   118 001152   120 001160   120 001167   122 001172   123 001173
124 001175   125 001203   126 001204   127 001220   128 001222   129 001223   130 001226
131 001231   133 001303   134 001320   135 001324   136 001335   137 001337   138 001340
139 001341   140 001342   142 001344   143 001345   144 001347   146 001350   147 001392
148 001360   150 001362   151 001364   152 001372   153 001403   154 001405   155 001423
156 001424   159 001463   161 001501   162 001514
```

APPENDIX E

Patch Utility Listing

This appendix is a listing of a patch utility corresponding to the dump utility in Appendix D. The utility, zp, is based on the installed Multics command, patch_ring_zero, documented in the _MPM System Programmers' Supplement_ <SPS73>. Zp uses the same algorithm as zd in Appendix D and operates under the same restrictions. A sample of its use is shown below. Lines typed by the user are underlined.

```
zp pds 660 123171163101 144155151156
660 104162165151 to 123171163101
661 144040040040 to 144155151156
Type "yes" if patches are correct: yes
```

As seen above, the command requests the user to confirm the patch before actually performing the patch. The patch shown above changes the user's project identification from Druid to SysAdmin.

```
COMPILATION LISTING OF SEGMENT zp
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1043.6 edt Wed
    Options: map

zp:   proc;

/* This procedure allows privileged users to patch locations in ring 0.
   If necessary the descriptor segment is patched to give access to patch a non-write
   permit segment */

dcl   targ char (tc) based (tp),
     (error_table_$noarg, error_table_$segknown) fixed bin ext,
     (code, i, tc, first, sw) fixed bin,
     (sdwp, segptr) ptr static,
      wdsegptr ptr,
      get_process_id_ ext entry returns (bit (36) aligned),
      processid bit (36) aligned,
      datai (0: 99) fixed bin static,
      data (0: 99) fixed bin(35),
      overlay (0:count-1) bit (36) aligned based,
      count fixed bin static,
     (tp, datap, dataip) ptr,
      dirname char (168),
      ename char (32),
      cv_oct_ entry (char (*)) returns (fixed bin (35)),
      cv_oct_check_ entry (char (*), fixed bin) returns (fixed bin (35)),
      ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
     (ioa_, ioa_$nnl) entry options (variable),
      ios_$read_ptr entry (ptr, fixed bin, fixed bin),
     (zg, zg$af) entry (ptr, fixed bin (35)),
      buffer char (16) aligned,
      cu_$arg_ptr ext entry (fixed bin, ptr, fixed bin, fixed bin),
      expand_path_ ext entry (ptr, fixed bin, ptr, ptr, fixed bin);

dcl 1 sdw based aligned,
     2 pad bit (30) unal,
     2 acc bit (6) unal;

dcl   save_acc fixed bin(35);

          datap = addr (data);                              /* get pointer to data area */
          count = 0;

          call cu_$arg_ptr (1, tp, tc, code);               /* pick up the first arg (name/number) */
          if code = error_table_$noarg | tc = 0 then do;
mess:          call ioa_ ("prz name/segno offset value1 ... valueN");
               return;
          end;
          i = cv_oct_check_ (targ, code);                   /* get segment number */
          if code ^= 0 then do;                             /* didn't give number */
               segptr = null ();                            /* if null() we're still in trouble */
               call ring0_get_$segptr ("", targ, segptr, code); /* so assume ring 0 name */
               if segptr = null () then do;
                    call ioa_ ("^a not found.", targ);
                    return;
               end;
          end;
          else segptr = baseptr (i);                        /* segment number given */

```

```
            call cu_$arg_ptr (2, tp, tc, code);
            if code = error_table_$noarg | tc = 0 then go to mess;          /* pick up second arg (first word to dump ) */
            first = cv_oct_ (targ);
            segptr = ptr (segptr, first);
            sdwp = ptr (baseptr (0), baseno (segptr));
            call ring0_get_$segptr ("", "wdseg", wdsegptr, code);

/* Now check the access on the segment about to be patched */

            datap = addr (data);
            dataip = addr (datai);
            call zg (sdwp, data (0));
            if data (0) = 0 then do;
                 call ioa_ ("p:  SDW = 0");
                 return;
            end;

                 if substr (datap -> sdw.acc, 4, 3) = "100"b then do;
                      call ioa_ ("p:  Master procedure.  SDW = ^w", data (0));
                      return;
                 end;
                 datap -> sdw.acc = "110010"b;
            call zg(ptr(wdsegptr,baseno(segptr)), save_acc);
            call zg$zf(ptr(wdsegptr, baseno(segptr)), data(0));
/* Now pick off the arguments */

            i = 2;
loop:       i = i + 1;
            call cu_$arg_ptr (i, tp, tc, code);                          /* get next argument */
            if code = error_table_$noarg | tc = 0 then go to endarg;
            datai (i-3) = cv_oct_ (targ);
            go to loop;                                                   /* convert i'th arg */
endarg:
            count = i - 3;
            if count = 0 then go to mess;
            datap -> overlay = segptr -> overlay;
            do i = 0 to count-1;
                 call ioa_ ("^6o  ^w to ^w", first+i, data (i), datai (i));
            end;

            call ioa_$nnl ("Type ""yes"" if patches are correct: ");
            call ios_$read_ptr (addr (buffer), 16, l);
            if l ^= 4 then go to reset;                            /* read in the answer */
            if substr (buffer, 1, 3) ^= "yes" then go to reset;




/* Now do the patches */

            segptr -> overlay = dataip -> overlay;

/* Now reset access (in dseg) if necessary */

reset: call zg$zf(ptr((wdsegptr), baseno(segptr)), save_acc);

```

```

        return;

    end;
```

```
                 NAMES DECLARED IN THIS COMPILATION.

IDENTIFIER                OFFSET    LOC STORAGE CLASS   DATA TYPE              ATTRIBUTES AND REFERENCES

NAMES DECLARED BY DECLARE STATEMENT.
acc                       0(30)         based           bit(6)                 level 2 packed unaligned dcl 31 set ref 74 78
buffer                           000260 automatic       char(16)               dcl 7 set ref 99 99 101
code                             000100 automatic       fixed bin(17,0)        dcl 7 set ref 40 41 45 46 48 56 57 61 86 87
count                            000160 internal static fixed bin(17,0)        dcl 7 set ref 38 90 92 93 93 94
cu_$arg_ptr                      000204 constant        entry                  external dcl 7 ref 40 56 86
cv_oct_                          000164 constant        entry                  external dcl 7 ref 58 88
cv_oct_check_                    000166 constant        entry                  external dcl 7 ref 45
date                             000106 automatic       fixed bin(35,0)        array dcl 7 set ref 37 66 68 69 75 88 95
date1                            000014 internal static fixed bin(17,0)        array dcl 7 set ref 67 88 95
date1p                           000256 automatic       pointer                dcl 7 set ref 67 109
datep                            000254 automatic       pointer                dcl 7 set ref 37 66 74 78 93
error_table_$noarg               000162 external static fixed bin(17,0)        dcl 7 ref 41 57 87
first                            000103 automatic       fixed bin(17,0)        dcl 7 set ref 58 59 95
i                                000101 automatic       fixed bin(17,0)        dcl 7 set ref 45 54 84 85 85 86 88 90 94 95 95 96
                                                                               99 100
ioa_                             000172 constant        entry                  external dcl 7 ref 42 58 78 75 95
ioa_$nnl                         000174 constant        entry                  external dcl 7 ref 96
ios_$read_ptr                    000176 constant        entry                  external dcl 7 ref 99
overlay                                 based           bit(36)                array dcl 7 set ref 93 93 109 109
ring0_get_$segptr                000170 constant        entry                  external dcl 7 ref 48 61
save_acc                         000264 automatic       fixed bin(35,0)        dcl 35 set ref 79 113
sdwp                             000010 internal static pointer                dcl 7 set ref 68 68
segptr                           000012 internal static pointer                dcl 7 set ref 47 48 49 54 59 59 60 73 79 80 80 93
                                                                               109 113 113
targ                                    based           char                   unaligned dcl 7 set ref 45 48 50 58 88
tc                               000102 automatic       fixed bin(17,0)        dcl 7 set ref 40 41 45 45 48 48 50 50 56 57 58 58
                                                                               86 87 88 88
tp                               000252 automatic       pointer                dcl 7 set ref 48 45 48 50 56 58 86 88
wdsegptr                         000104 automatic       pointer                dcl 7 set ref 61 79 79 80 80 113 113
zg                               000200 constant        entry                  external dcl 7 ref 68 79
zg$zf                            000202 constant        entry                  external dcl 7 ref 80 113

NAMES DECLARED BY DECLARE STATEMENT AND NEVER REFERENCED.
dirname                                 automatic       char(168)              unaligned dcl 7
ename                                   automatic       char(32)               unaligned dcl 7
error_table_$segknown
                                        external static fixed bin(17,0)        dcl 7
expand_path_                     000000 constant        entry                  external dcl 7
get_process_id_                  000000 constant        entry                  external dcl 7
pad                                     based           bit(30)                level 2 packed unaligned dcl 31
processid                               automatic       bit(36)                dcl 7
sdw                                     based           structure              level 1 packed dcl 31
sw                                      automatic       fixed bin(17,0)        dcl 7

NAMES DECLARED BY EXPLICIT CONTEXT.
endarg                           000635 constant        label                  dcl 98 ref 87 98
loop                             000555 constant        label                  dcl 85 ref 85 89
mess                             000132 constant        label                  dcl 42 ref 42 57 92
reset                            000770 constant        label                  dcl 113 ref 100 101 113
zp                               000072 constant        entry                  external dcl 1 ref 1

NAMES DECLARED BY CONTEXT OR IMPLICATION.
addr                                                    builtin function       internal ref 37 66 67 99 99
baseno                                                  builtin function       internal ref 68 79 79 80 80 113 113
baseptr                                                 builtin function       internal ref 54 68
```

```
null                                                            builtin function        internal ref 47 49
ptr                                                             builtin function        internal ref 59 60 79 79 80 80 113 113
substr                                                          builtin function        internal ref 74 101

STORAGE REQUIREMENTS FOR THIS PROGRAM.

           Object     Text       Link       Symbol     Defs       Static
Start           0        0       1130         1336     1012         1140
Length       1526     1012        206          156      116          176

External procedure zp uses 244 words of automatic storage

THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
r_e_as              call_ext_out_desc   call_ext_out        return              copy_words          ext_entry
rpd_loop_1_lp_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
cu_$arg_ptr                         cv_oct_                             cv_oct_check_                       ioa_
ioa_$nnl                            ios_$read_ptr                       ring0_get_$segptr                   zp
zp$zf

THE FOLLOWING EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.
error_table_$noarg


   LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC
      1 000071        37 000077        38 000101        40 000103        41 000121        42 000132        43 000147
     45 000156        46 000202        47 000204        48 000207        49 000243        50 000250        51 000301
     53 000302        54 000303        56 000310        57 000327        58 000340        59 000364        60 000372
     61 000402        66 000430        67 000432        68 000435        69 000445        70 000447        71 000465
     74 000456        75 000472        76 000513        78 000514        79 000517        80 000535        84 000553
     85 000555        86 000556        87 000573        88 000604        89 000634        90 000635        92 000640
     93 000641        94 000647        95 000656        96 000713        98 000715        99 000732       100 000751
    101 000734       109 000760       113 000770       116 001010
```

APPENDIX F

Set Dates Utility Listing

This appendix is a listing of the set dates utility described in Section 3.4.4. The get entry point takes a pathname as an argument and remembers the dates on the segment at that time. The set entry point takes no arguments and sets the dates on the segment to the values at the time of the call to the get entry point. Set remembers the pathname as well as the dates and may be called repeatedly to handle the deactivation problem discussed in Section 3.4.4.

```
COMPILATION LISTING OF SEGMENT get
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1841.1 edt Wed
    Options: map

get:
      proc;

/* Entry point to get the dates from a segment */


            dcl
            cu_$arg_ptr entry (fixed bin, ptr, fixed bin, fixed bin),
            expand_path_ entry (ptr, fixed bin, ptr, ptr, fixed bin),
            com_err_ entry options (variable),
            hcs_$status_long entry (char (*), char (*), fixed bin (1), ptr, ptr, fixed bin),
            hcs_$set_dates entry (char (*), char (*), ptr, fixed bin);
            dcl
            argp ptr,
            argl fixed bin,
            code fixed bin,
            dir char (168) int static init (" "),
            entry char (32) int static init (" "),
            arg char (argl) based (argp),
            bp ptr;
            dcl
            1 time aligned internal static,
            2 (dtem, dtd, dtu, dtm) bit (36) unaligned;
            dcl
            1 branch aligned,
            2 (type bit (2), nnames bit (16), nrp bit (18), dtm bit (36), dtu bit (36), mode bit (5), padding
            bit (13), records bit (18), dtd bit (36), dtem bit (36), acct bit (36), curlen bit (12), bitcnt
            bit (24), did bit (4), mdid bit (4), copysw bit (1), pad2 bit (9), nbs (0:2) bit (6), uid bit (36)
            ) unal;
            call cu_$arg_ptr (1, argp, argl, code);          /* get relative pathname from command line */
            if code ^= 0 then
                do;
err1:

                call com_err_ (code, "get");
                return;
            end;
            call expand_path_ (argp, argl, addr (dir), addr (entry), code);
            if code ^= 0 then
                do;
error:

                call com_err_ (code, "get", arg);
                return;
            end;
            bp = addr (branch);
            call hcs_$status_long (dir, entry, 1, bp, null (), code); /* read out dates on segment */
            if code ^= 0 then go to error;

            time.dtem = branch.dtem;                                  /* save dates in internal static */
            time.dtd = branch.dtd;
            time.dtu = branch.dtu;
            time.dtm = branch.dtm;
            return;

set:
            entry;
```

```

/* Entry to set the dates on a segment to the values at the time of the get call */

          call hcs_$set_dates (dir, entry, addr (time), code); /* set the dates */
          if code ^= 0 then go to err1;
     end;
```

```
          NAMES DECLARED IN THIS COMPILATION.

IDENTIFIER                  OFFSET     LOC STORAGE CLASS   DATA TYPE                ATTRIBUTES AND REFERENCES

NAMES DECLARED BY DECLARE STATEMENT.
acct                         6       000106 automatic       bit(36)                  level 2 packed unaligned dcl 25
arg                                         based           char                     unaligned dcl 14 set ref 40
argl                                 000102 automatic       fixed bin(17,0)          dcl 14 set ref 30 37 40 40
argp                                 000100 automatic       pointer                  dcl 14 set ref 30 37 40
bitcnt                       7(12)   000106 automatic       bit(24)                  level 2 packed unaligned dcl 25
bp                                   000104 automatic       pointer                  dcl 14 set ref 44 45
branch                               000106 automatic       structure                level 1 packed dcl 25 set ref 44
code                                 000103 automatic       fixed bin(17,0)          dcl 14 set ref 30 31 33 37 38 40 45 46 59 60
com_err_                             000104 constant        entry                    external dcl 8 ref 33 40
copysw                      10(08)   000106 automatic       bit(1)                   level 2 packed unaligned dcl 25
cu_$arg_ptr                          000100 constant        entry                    external dcl 8 ref 30
curlen                       7       000106 automatic       bit(12)                  level 2 packed unaligned dcl 25
did                         10       000106 automatic       bit(4)                   level 2 packed unaligned dcl 25
dir                                  000010 internal static char(168)                initial unaligned dcl 14 set ref 37 37 45 59
dtd                          4       000106 automatic       bit(36)                  level 2 packed unaligned dcl 25 set ref 49
dtd                          1       000072 internal static bit(36)                  level 2 packed unaligned dcl 22 set ref 49
dtep                         5       000106 automatic       bit(36)                  level 2 packed unaligned dcl 25 set ref 48
dtem                                 000072 internal static bit(36)                  level 2 packed unaligned dcl 22 set ref 48
dtm                          3       000072 internal static bit(36)                  level 2 packed unaligned dcl 22 set ref 51
dtm                          1       000106 automatic       bit(36)                  level 2 packed unaligned dcl 25 set ref 51
dtu                          2       000072 internal static bit(36)                  level 2 packed unaligned dcl 22 set ref 50
dtu                          2       000106 automatic       bit(36)                  level 2 packed unaligned dcl 25 set ref 50
entry                                000062 internal static char(32)                 initial unaligned dcl 14 set ref 37 37 45 59
expand_path_                         000102 constant        entry                    external dcl 8 ref 37
hcs_$set_dates                       000110 constant        entry                    external dcl 8 ref 59
hcs_$status_long                     000106 constant        entry                    external dcl 8 ref 45
mdid                        10(04)   000106 automatic       bit(4)                   level 2 packed unaligned dcl 25
mode                         3       000106 automatic       bit(5)                   level 2 packed unaligned dcl 25
nbs                         10(10)   000106 automatic       bit(6)                   array level 2 packed unaligned dcl 25
nnames                       0(02)   000106 automatic       bit(16)                  level 2 packed unaligned dcl 25
nrp                          0(18)   000106 automatic       bit(18)                  level 2 packed unaligned dcl 25
pad2                        10(09)   000106 automatic       bit(9)                   level 2 packed unaligned dcl 25
padding                      3(05)   000106 automatic       bit(13)                  level 2 packed unaligned dcl 25
records                      3(18)   000106 automatic       bit(18)                  level 2 packed unaligned dcl 25
time                                 000072 internal static structure                level 1 packed dcl 22 set ref 59 59
type                                 000106 automatic       bit(2)                   level 2 packed unaligned dcl 25
uid                         11       000106 automatic       bit(36)                  level 2 packed unaligned dcl 25

NAMES DECLARED BY EXPLICIT CONTEXT.
err1                                 000041 constant        label                    dcl 33 ref 33 60
error                                000106 constant        label                    dcl 40 ref 40 46
get                                  000013 constant        entry                    external dcl 1 ref 1
set                                  000221 constant        entry                    external dcl 54 ref 54

NAMES DECLARED BY CONTEXT OR IMPLICATION.
addr                                                        builtin function         internal ref 37 37 37 37 44 59 59
null                                                        builtin function         internal ref 45 45

STORAGE REQUIREMENTS FOR THIS PROGRAM.

          Object    Text      Link      Symbol    Defs      Static
Start          0       0       350         462     260         360
Length       632     260       112         136      67         102

External procedure get uses 140 words of automatic storage
```

```
THE FOLLOWING EXTERNAL OPERATORS ARE USED BY THIS PROGRAM.
call_ext_out_desc   call_ext_out        return              ext_entry

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
com_err_                      cu_$arg_ptr                   expand_path_                  hcs_$set_dates
hcs_$status_long

NO EXTERNAL VARIABLES ARE USED BY THIS PROGRAM.


   LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC      LINE    LOC
      1 000012        30 000020        31 000037        33 000041        35 000050        37 000061        38 000104
     40 000106        42 000141        44 000142        45 000144        46 000204        48 000206        49 000211
     50 000213        51 000215        52 000217        54 000220        59 000226        60 000255        64 000257
```

GLOSSARY

Access

"The ability and the means to approach, communicate with (input to or receive output from), or otherwise make use of any material or component in an ADP System." <DOD73>

Access Control List (ACL)

"An access control list (ACL) describes the access attributes associated with a particular segment. The ACL is a list of user identifications and respective access attributes. It is kept in the directory that catalogs the segment." <HIS73>

Active Segment Table (AST)

The AST contains an entry for every active segment in the system. A segment is "active" if its page table is in core. The AST is managed with least recently used algorithm.

Argument Validation

On calls to inner-ring (more privileged) procedures, argument validation is performed to ensure that the caller indeed had access to the arguments that have been passed to ensure that the called, more privileged procedure does not unwittingly access the arguments improperly.

Arrest

"The discovery of user activity not necessary to the normal processing of data which might lead to a violation of system security and force termination of the activity." <DOD73>

Breach

"The successful and repeatable defeat of security controls with or without an arrest, which if carried to consummation, could result in a penetration of the system. Examples of breaches are:
a. Operation of user code in master mode;
b. Unauthorized acquisition of I.D. password or file access passwords; and
c. Accession to a file without using prescribed operating system mechanisms." <DOD73>

Call Limiter

The call limiter is a hardware feature of the HIS 6180 which restricts calls to a gate segment to a specified block of instructions (normally a transfer vector) at the base of the segment.

Date Time Last Modified (DTM)

The date time last modified of each segment is stored in its parent directory.

Date Time Last Used (DTU)

The date time last used of each segment is stored in its parent directory.

Deactivation

Deactivation is the process of removing a segments page table from core.

Descriptor Base Register (DBR)

The descriptor base register points to the page table of the descriptor segment of the process currently executing on the CPU.

Descriptor Segment (DSEG)

The descriptor segment is a table of segment descriptor words which identifies to the CPU to which segments, the process currently has access.

Directory

"A directory is a segment that contains information about other segments such as access attributes, number of records, names, and bit count." <HIS73>

emergency_shutdown

"This mastermode module provides a system reentry point which can be used after a system crash to attempt to bring the system to a graceful stopping point." <SPS73>

Fault Intercept Module (fim)

The fim is a ring 0 module which is called to handle most faults. It copies the saved machine state into an easily accessible location and calls the appropriate fault handler (usually the signaller).

Gate Segment

A gate segment contains one or more entry point used on inward calls. A gate entry point is the only entry in a inner ring that may be called from an outer ring. Argument validation must be performed for all calls into gate segments.

General Comprehensive Operating Supervisor (GCOS)

GCOS is the operating system for the Honeywell 600/6000 line of computers. It is very similar to other conventional operating systems and has no outstanding security features.

HIS 645

The Honeywell 645 is the computer originally designed to run Multics. It is a modification of the HIS 635 adding paging and segmentation hardware.

HIS 6180

The Honeywell 6180 is a follow-on design to the HIS 645. The HIS 6180 uses the advanced circuit technology of the HIS 6080 and adds paging and segmentation hardware. The primary difference between the HIS 6180 and the HIS 645 (aside from performance improvements) is the addition of protection ring hardware.

hcs_

The gate segment hcs_ provides entry into ring 0 for most user programs for such functions as creating and deleting segments, modifying ACL's, etc.

hphcs_

The gate segment hphcs_ provides entry into ring 0 for such functions as shutting the system down, hardware reconfiguration, etc. Its access is restricted to system administration personnel.

ITS Pointer

An ITS (Indirect To Segment) Pointer is a 72-bit pointer containing a segment number, word number, bit offset, and indirect modifier. A Multics PL/I aligned pointer variable is stored as an ITS pointer.

Known Segment Table (KST)

The KST is a per-process table which associates segment numbers with segment names. Details of its organization and use may be found in Organick. <ORG72>

Linkage Segment

"The linkage segment contains certain vital symbolic data, descriptive information, pointers, and instructions that are needed for the linking of procedures in each process." <ORG72>

Master Mode

When the HIS 645 processor is in master mode (as opposed to slave mode), any processor instruction may be executed and access control checking is inhibited.

Multics

Multics, the Multiplexed Information and Computing Service, is the operating system for the HIS 645 and HIS 6180 computers.

Multi-Level Security Mode

"A mode of operation under an operating system (supervisor or executive program) which provides a capability permitting various levels and categories or compartments of material to be concurrently stored and processed in an ADP system. In a remotely accessed resource-sharing system, the material can be selectively accessed and manipulated from variously controlled terminals by personnel having different security clearances and access approvals. This mode of operation can accomodate the concurrent processing and storage of (a) two or more levels of classified data, or (b) one or more levels of classified data with unclassified data depending upon the constraints placed on the systems by the Designated Approving Authority." <DOD73>

OS/360

OS/360 is the operating system for the IBM 360 line of computers. It is very similar to other conventional operating systems and has no outstanding security features.

Page

Segments may be broken up into 1024 word blocks called pages which may be stored in non-contiguous locations of memory.

Penetration

"The successful and repeatable extraction and identification of recognizable information from a protected data file or data set without any attendant arrests." <DOD73>

Process

"A process is a locus of control within an instruction sequence. That is, a process is that abstract entity which moves through the instructions of a procedure as the procedure is executed by a processor." <DEN66>

Process Data Segment (PDS)

The PDS is a per-process segment which contains various information about the process including the user identification and the ring 0 stack. The PDS is accessible only in ring 0 or in master mode.

Process Initilization Table (PIT)

The PIT is a per-process segment which contains additional information about the process. The PIT is readable in ring 4 and writable only in ring 0.

Protection Rings

Protection rings form an extension to the traditional master/slave mode relationship in which there are eight hierarchical levels of protection numbered 0 - 7. A given ring N may access rings N through 7 but may only call specific gate segments in rings 0 to N-1.

Reference Monitor

The reference monitor is that hardware/software combination which must monitor <u>all</u> references by any program to any data anywhere in the system to ensure the security rules are followed.

a. The monitor must be tamper proof.

b. The monitor must be invoked for <u>every</u>

reference to data anywhere in the system.
c. The monitor must be small enough to be proven correct.

Segment

A segment is the logical atomic unit of information in Multics. Segments have names and unique protection attributes and may contain up to 256K words. Segments are directly implemented by the HIS 645 and HIS 6180 hardware.

Segment Descriptor Word (SDW)

An sdw is a single entry in a Descriptor Segment. The SDW contains the absolute address of the page table of a segment (if one exists) or an indication that the page table does not exist. The SDW also contains the access control information for the segment.

Segment Loading Table (SLT)

The SLT contains a list of segments to be used at the time the system is brought up. All segments in the SLT come from the system tape.

signaller

"signaller is the hardcore ring privileged procedure responsible for signalling all fault and interrupt-produced errors." <SPS73>

Slave Mode

When the HIS 645 processor is in slave mode, certain processor instructions are inhibited and access control checking is enforced. The processor may enter master mode from slave mode only by signalling a fault of some kind.

Stack Base Register

The stack base register contains the segment number of the stack currently in use. In the original design of Multics, the stack base was locked so that interrupt handlers were guaranteed that it always pointed to a writable segment. This restriction was later removed allowing the user to change the stack base arbitrarily.

subverter

The subverter is a procedure designed to test the reliability of security hardware by periodically attempting illegal accesses.

Trap door

Trap doors are unnoticed pieces of code which may be inserted into a system by a penetrator. The trap door would remain dormant within the software until triggered by the agent. Trap doors inserted into the code implementing the reference monitor could bypass any and all security restrictions on the systems. Trap doors can potentially be inserted at any time during software development and use.

WWMCCS

WWMCCS, the World Wide Military Command and Control System, is designed to provide unified command and control functions for the Joint Chiefs of Staff. As part of the WWMCCS contract for procurement of a large number of HIS 6000 computers, a set of software modifications were made to GCOS, primarily in the area of security. The WWMCCS GCOS security system was found to be no more effective than the unmodified GCOS security, due to the inherent weaknesses of GCOS itself.