1-22-96

SANDIA REPORT

SAND95-2751 • UC-700
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Printed January 1996

STOCKPILE SURVEILLANCE: Past and Future

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for the United States Department of Energy
under Contract DE-AC04-94AL85000

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ABSTRACT

The nuclear weapons program is entering a new era. Major features of the past era — continuous entry of new weapons into the stockpile, a large production capacity, and underground nuclear testing — are no longer part of the weapons program. New issues must be addressed such as how the nuclear weapons currently in the stockpile will age beyond their originally anticipated lifetime, what the workload for the weapons production complex will be, and what facilities and programs the DOE and the nuclear design laboratories need to assure the safety and reliability of an aging stockpile in this new era. The history of the stockpile provides a useful perspective on these questions. The purpose of this paper is to review the traditional methods of assessment of stockpiled weapons, to provide an updated and comprehensive summary of the results and lessons learned from this experience, and to present recommendations for an improved assessment program in the future. This paper was written for a wide audience to provide historical information pertinent to the issues faced by the DOE and the nuclear design laboratories. It is necessarily restricted with respect to specific details of past problems.

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LOS ALAMOS
National Laboratory

August 7, 1995

Dr. Victor H. Reis
Assistant Secretary for Defense Programs
U.S. Department of Energy
Washington, DC 20585

Dear Dr. Reis:

In response to your request for a study updating the stockpile lifetime database and a three lab view of the principal messages the data provide, we are forwarding the document, *Stockpile Surveillance: Past and Future*, which we believe is a good representation of 35 years of experience in managing sealed-pit weapons in the stockpile. These data may not be complete and we will continue to review the history of the stockpile to look for other occurrences. However, we believe that the data included here provide a compelling reason to maintain an experienced nuclear weapons staff at the laboratories — problems have been found in the stockpile that must be investigated and, when necessary, corrective actions must be taken. This case is even stronger for the future with a steadily aging stockpile, a reduced production capacity for making corrective actions, and without underground nuclear testing. Our recommendation is to improve the surveillance program, where possible, for both nuclear and non-nuclear components to make it more predictive and to enable us to address problems in the physics package without underground testing.

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SUMMARY

The main points of this paper are as follows:

- The US nuclear weapon stockpile is entering a different era. Continuous introduction of new weapons into the stockpile, a large production capacity, and underground nuclear testing played important roles in how the nuclear weapons stockpile was managed in the past. These are no longer elements of the nuclear weapons program. Adjustments need to be made to compensate for the loss of these elements.

- The history of the stockpile indicates that problems have been found in both nuclear and non-nuclear components through a variety of methods including the Stockpile Evaluation Program, stockpile management activities, underground nuclear tests, and research activities. Changes have been made to the stockpile when necessary to assure safety, performance, and reliability. There have been problems found in each of the weapon types expected to be in the stockpile in the year 2000. It is reasonable to expect problems will continue to arise in the stockpile as it ages beyond the original design expectations.

- The Stockpile Evaluation Program, which has evaluated sealed-pit weapons since 1958, will continue to be essential for determining the health of the nuclear weapons stockpile. This program has evolved since 1958 and must continue to change to assure the safety, performance, and reliability of the stockpile in this new era.

- Based on history, a minimum workload of resolving one or two "actionable" problems per year and implementing one or two changes per year can be expected for the stockpile as it ages. However, extrapolation of past experience with older weapon types should be used cautiously because of the limited number of older units which have been tested through the Stockpile Evaluation Program and because of the differences in technologies between older weapons and more modern weapons.

- Recommendations for the future are focused on adding more predictive capabilities to the existing Stockpile Evaluation Program to maintain the required levels of safety, performance, and reliability for both nuclear and non-nuclear components in an era of older stockpile weapons and a reduced production capacity. Historical data on aging characteristics do not exist for some materials in the stockpile, and some materials are presently undergoing chemical changes. Therefore, development of a database of material aging characteristics is recommended. Nuclear components have a particular problem in that without underground nuclear testing, full functional testing is not possible. Therefore, new methods are recommended for evaluating nuclear components.

1. INTRODUCTION

Dramatic changes in the international scene over the past six years have led to fundamental changes in the nature of the US nuclear weapon program. The extent of these changes is reflected in current planning guidelines for the year 2003 and beyond which outline an active stockpile smaller than the US has had at any time since 1959. This stockpile will have been reduced by treaty, Presidential initiative, and service requirements. The last new weapon in this stockpile was built in 1990. The production complex, which will be responsible for the components necessary for any changes to the stockpile and for the eventual replacement of current weapons, is being downsized accordingly. When the current weapons were designed, their anticipated lifetime was only about 20 years; there has never been a weapon type in the stockpile for more than 35 years. The consequences of the present plan for downsizing could be that some weapons will remain in the stockpile for more than 40 years. In order to develop plans for the size and composition of the future nuclear weapons complex, we need to be able to make the best possible estimates of the rate of anticipated repairs and retrofits of these enduring stockpile weapons.

Until recently there has been no expectation that weapons would remain in the stockpile longer than they have in the past. Continuous modernization to improve safety, reliability, and performance kept the stockpile young as new weapon types replaced old ones. Now, as shown in Figure 1, with no new models, we have a steadily aging nuclear deterrent. The average age of the stockpile has never approached the typical lifetime specified in the weapon requirements (~ 20 years for the most modern US nuclear weapons). The stockpile reached its oldest average age in 1991 after all new production ceased. Following the retirement (due to Presidential initiative) of many older, non-strategic weapons, the average age dropped in 1992. However, the stockpile average age will now climb roughly one year per year and will reach the 20 year mark by 2005, at which time the oldest weapons (W62) would be about 35 years old.

Continuous evaluation of the health of the stockpile has always been a major part of the US nuclear weapons program. Since the introduction of sealed-pit weapons more than 35 years ago, a formal surveillance program of non-nuclear laboratory and flight testing has been in existence. More than 13,800 weapons have now been evaluated in this program. In addition, there have been nuclear tests of stockpiled weapons and components (68 underground tests since 1972 have involved components or designs from weapons already introduced into the stockpile). The Stockpile Evaluation Program[1] with its reliance on functional testing has provided information that can be used in the statistical analysis of non-nuclear component reliability and has been the principal mechanism for discovering defects and initiating subsequent repairs and retrofits. Results of this program, along with information pertaining to problems found outside of the Stockpile Evaluation Program, have been compiled in an extensive database which is a valuable source of information for analysis of defect and repair rates.

Not all aspects of a nuclear weapon can be statistically assessed through the Stockpile Evaluation Program. Certification that nuclear weapons meet the DOE design requirements for nuclear detonation safety[2] is made based on test data, computer analysis, and technical judgement and cannot be rigorously validated through surveillance. Neither the Stockpile Evaluation Program nor nuclear testing have provided a statistical basis for the assessment of the reliability of the nuclear explosive package. The nuclear explosive package has traditionally been assigned a reliability of 1.0 in formal reporting. The confidence in the performance of the nuclear explosive package has been

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[1] This program is formally known as the New Material and Stockpile Evaluation Program within the Department of Energy and as the Quality Assurance and Reliability Test (QART) within the Department of Defense. Although stockpile evaluation of non-sealed-pit weapons was ongoing prior to 1958, the term Stockpile Evaluation Program will be used to refer to the evaluation of sealed-pit weapons which began in 1958.

[2] Probability of an unintended nuclear detonation shall not exceed 1 in 1 billion per weapon lifetime under normal environments and not exceed 1 in 1 million per weapon exposure under abnormal environments.

based on underground nuclear test data, above ground experiments, computer simulations, surveillance data, and technical judgement. All of these techniques, as well as the calculational and non-nuclear testing done during development programs of other weapons and other R&D programs, have provided important insights into nuclear explosive package performance and safety and, at times, have led to changes in stockpiled weapons. Documentation in the formal database of those problems relating to stockpiled weapons found through methods outside the Stockpile Evaluation Program and the subsequent corrective actions has been inconsistent; recent analysis of the old database identified a significant number of omissions and inconsistencies.

One purpose of the present study — the basis of this report — is to rectify the situation and ensure that the data are as current, complete, and appropriately expanded in scope as possible so that the database can be used as an accurate historical record for predicting the future. At this time, there are about 30 occurrences which are not readily amenable to incorporation in the database. These occurrences cover primary and secondary components for older weapons. Additional research is being done to make these records complete for inclusion in the database. Appendix G (classified) contains the complete list of primary and secondary findings considered in this report. Although not yet included in the database, these occurrences have been incorporated into this study and are included in the figures presented.

The updated database is referred to as the "Defects Database" or "Findings Database." It now contains more than 2,400 entries, cross-referenced by more than 40 descriptor fields. More than 800 entries are unique, and more than 370 cases have resulted in some kind of action due to safety or reliability concerns (see Classified Appendix F). These 370+ cases affected non-nuclear components in 38 weapon types. The problems included in this document which have required action to the nuclear components (110) affected 39 weapon types. Considering both nuclear and non-nuclear components, 46 of the 50 weapon types covered in this report have had at least one problem requiring action to resolve. These problems include many situations in which all weapons of a particular weapon type (thousands, in some cases) were affected and a system-wide repair was required.

Figure 2 shows that problems which require investigation continue to appear in the stockpile to this day. Some of these are grave and warrant corrective action (Figure 3). The details of these problems could become even more important as the weapon types currently in the stockpile age.

Traditional methods of assessment have worked well for the US. Today, however, without the benefit of a steady stream of new weapon development projects and without underground testing, traditional methods of surveillance may not be sufficient to identify the full range of stockpile problems. In addition, the limited size of the future production complex may make "crash" repair programs impractical. Lead times as long as possible are needed in order that repairs and retrofits be completed before the reliability of the deployed weapons degrades. This will require development of entirely new methods of assessment as well as improved computational prediction. Thus a significant addition to the current surveillance, evaluation, and assessment of the stockpile is required. An Enhanced Surveillance Program is being developed to provide the technologies and methods for this addition.

The purposes of this document are to review the traditional methods of assessment of stockpiled weapons, to provide an updated and comprehensive summary of the results and lessons learned from this experience, and to present recommendations for an improved assessment program in the future. In the course of this study, a review of the history of nuclear weapons in the stockpile was conducted in an attempt to include all of the problems that have occurred. In some cases the history is not well documented, and additional problems may be identified after the release of this document. Also there is a rich history of weapon development, including design dead-ends and problems that were overcome during development, which is not addressed in this document but is an important part of the DOE experience with nuclear weapons.

The report has several appendices which contain detailed classified information about specific problems found in the stockpile. Also included in the appendices is a classified discussion of the historical role of nuclear testing in identifying and correcting stockpile problems.

2. TRADITIONAL METHODS OF ASSESSMENT

As mentioned in the introduction, one of the critical roles of the DOE nuclear weapons program is to maintain nuclear weapons once they have entered the stockpile. This role includes assessing the health of the stockpile. The stockpile evaluation program is the most visible activity associated with assessing the health of the stockpile. However, ongoing weapons research and development at the three design laboratories and underground nuclear testing have played a part in assessing the stockpile and in making corrective changes when needed. Section 2.1 places in perspective the role of underground nuclear testing with respect to assessing the stockpile. Section 2.2 describes the stockpile surveillance and evaluation program. Section 2.3 gives a brief summary of how weapon reliability is assessed.

2.1. Underground Nuclear Testing

Underground nuclear tests have been a critical component of the nuclear weapons program. They have contributed to a broad range of activities from development of new weapons, to stockpile confidence tests, to tests that either identified a concern or showed that remedial actions were not needed. Underground nuclear tests are the only way to test the full operation of a weapon, and the nuclear explosive package cannot be tested in its intended mode of operation in any other way. However, the US has not conducted a sufficient number of nuclear tests for any one weapon type to provide a statistical assessment of reliability for nuclear explosive performance.

Although underground tests were never a part of the formal stockpile evaluation program , they played an important role in maintaining the safety and performance of the weapons in the stockpile. Every advantage was taken of developmental nuclear tests to eliminate potential nuclear explosive problems. In some cases, nuclear testing during development of one weapon type uncovered a problem that was pertinent to a previous design already in the stockpile which then had to be corrected. Nuclear tests identified certain classes of stockpile problems not observable in the surveillance program, such as the lack of one-point safety for several weapon types previously deployed in the stockpile. Nuclear tests have been used to resolve issues raised by the surveillance program, such as whether a particular corrosion problem affected yield. They have been used to verify the efficacy of design changes. For example, the adequacy of certain mechanical safing techniques was determined with underground testing. In the case of a catastrophic defect, underground tests have been used to certify totally new designs to replace an existing design. Finally, in some cases, nuclear testing proved that a potential problem (that could have required an expensive fix) did not exist.

Beginning in the late 1970s, the Department of Defense and Department of Energy agreed to a formal series of underground tests of weapons withdrawn from the stockpile. These tests were referred to as Stockpile Confidence Tests. They differed from development nuclear tests in that the weapon was from actual production, had experienced stockpile conditions, and had minimal changes made to either nuclear or non-nuclear components prior to the test. Including four tests from the early 1970s which were not officially called Stockpile Confidence Tests but for all purposes were, there have been 17 such tests since 1972. A test for each of the weapon types expected to remain in the stockpile well into the next century has been conducted. Although the yield was lower than expected for one of these tests, there were no catastrophic failures in any of the 17 confidence tests. The cause for the low yield was evaluated, and action was taken to correct this problem. The corrective action was confirmed by a second Stockpile Confidence Test for this weapon type.

In addition to the Stockpile Confidence Tests, there have been at least 51 additional underground nuclear tests since 1972 involving nuclear components from the stockpile, components from the actual weapon production line, or components built according to stockpile design specifications and tested after system deployment. These tests had objectives which included weapon effects, weapon R&D, confirmation of a fix or investigation of safety or reliability concerns. Three of these tests (in addition to one Stockpile Confidence Test) revealed or confirmed a problem that required corrective action. Four tests (in addition to three Stockpile Confidence Tests) confirmed a fix to an identified problem. Additionally, five tests were performed to investigate safety concerns affecting three different warhead types. These five tests verified that a problem did not exist.

The core capabilities that were developed to eliminate potential problems in new weapon designs must now be employed to assess stockpile aging problems in a future without nuclear testing. However, in the absence of nuclear testing, the ability to assess nuclear components is more difficult; new methods of assessment, discussed later, will have to be developed to help to compensate for this loss.

2.2. Stockpile Evaluation Program

The purpose of the stockpile surveillance and evaluation program is to provide confidence that the reliability, performance, and safety of fielded and stockpiled weapons are maintained. Components and assemblies randomly sampled from the stockpile and new production are subjected to materials and functional tests. (Only non-nuclear components undergo functional testing.) Laboratory tests are used to evaluate weapon components in controlled, repeatable environments. Flight tests are concerned primarily with the integration and functionality of electrical and mechanical subsystems but also test some aspects of the nuclear explosive package.

Surveillance and evaluation of the condition of the US nuclear stockpile have been important aspects of the nuclear weapons program since the decision to stockpile these weapons. The stockpile surveillance function was formalized at Sandia in 1948 and became part of the 1954 AEC-SFO/Sandia Memorandum of Understanding. The advent of sealed-pit weapons eliminated field surveillance operations conducted by military service personnel under supervision of DOE personnel. A new program involving the return of stockpile weapons to the Department of Energy for test and evaluation was implemented. (Currently, this testing is done at the Pantex plant near Amarillo, TX.) A fraction of the sampled weapons would be dismantled for inspection of the nuclear explosive package components.

The first stockpile weapon sample returns were received in 1958. These were samples from the W25 and B28 populations. Every six months 50 samples of each type were drawn from the stockpile and tested. The decision to test 50 was arbitrary, as was the six-month period. After three cycles of such testing, enough experience had been developed to determine that the sample period could be extended to one year. Most of the findings and defects discovered in these initial cycles were related to design and production. With the prospect of nearly 20 new weapon types entering the stockpile, the decision was made in 1959 to sample and test newly produced units to reduce the time before discovery of design and production defects. The program then became known as the New Material and Stockpile Evaluation Program.

New material sampling was conducted throughout the production phase of a weapon system. Units were sampled at a rate that gradually decreased during the first six months from one out of every two produced down to a steady rate for the remainder of production. The steady rate depended on the total number of weapons produced and the duration of production. The higher sampling rate during the first six months of production (about three times greater than any other six month interval) was an attempt to identify and resolve those design and production problems that historically appeared during initial production.

A weapon system was subjected to three different sampling rates for evaluation during its stockpile lifetime. The highest rate was during the first six months of production, followed by a combination of new material and stockpile samples for the remainder of production, and finally just the stockpile samples until two years before retirement when sampling ceased. Theoretically, after several sample cycles there is high confidence that systematic design defects and systematic manufacturing defects not related to aging will have been identified. However, as new testing techniques have been incorporated and new defect mechanisms have been recognized, a few design and production related defects have been discovered many sample cycles after a weapon type has entered the stockpile.

In 1960 the maximum stockpile sample was reduced from 50 to 45 per year to correspond to a statistical statement — testing provided a 90% confidence that the weapon functionality was at least 95% (referred to as a 90/95 sample). This statistical statement provided a rationale for the quantity sampled but is valid only if a potential defect could be found by any test conducted. Both the new material samples and the stockpile samples were tested exclusively in the laboratory, but it was only possible to test one specific fuzing option for each sample. Thus, the statistical statement provided a guideline but could not be considered rigorous for producing a confidence statement about weapon reliability.

In 1963 the Department of Defense agreed to an AEC proposal to include flight testing that would address some aspects of the performance of the entire weapon system. It was also at this time that the evaluation program was broadened to consider all of the conditions in which weapons in the stockpile were expected to function. Test realism was further elevated in priority.

By 1965 enough experience had been gained from the evaluation program to allow the stockpile sample size to be reduced to a 90/90 sample (about 22 samples per system per year). The motivation for this reduction was to reduce the cost and safety concerns associated with moving weapons to the DOE assembly plants for testing. The reduction was possible because the frequency of finding defects was not great enough to warrant such a large sample. The desire to anticipate problems due to aging was addressed in 1970 when Accelerated Aging Units were first selected from production and subjected to accelerated thermal cycling patterns. This form of testing provided an early opportunity to discover material compatibility problems which escaped detection during development, production, and new material testing.

In the mid 1980s the stockpile sample was again reduced by half, and the statistical statement guiding the sample size became a 90% confidence that the functionality was at least 90% following a two-year sampling period (90/90/2). At this same time, the Significant Finding Investigation process was strengthened by making it more rigorous and more formalized. All findings and defects that may have an impact on weapon safety, use control, or reliability are investigated with monthly reports on the status of these investigations.

Today with no weapons in production, only the stockpile portion of the Stockpile Evaluation Program is active. Typically, 11 samples of each weapon type are randomly taken from the stockpile each year. These samples are subjected to some disassembly and inspection prior to testing, and the non-nuclear components are then assembled into a laboratory test bed for system level testing or into a Joint Test Assembly for flight testing. Although there are variations, in general the nuclear explosive package from one sample per year per weapon type is destructively examined for dimension and material composition changes. This sample is retired from the stockpile. For the remaining ten samples, the non-nuclear components, which have not been destroyed during these tests, are reassembled into the weapon along with replacement parts (made during production for this purpose) and the nuclear packages and then the weapons are returned to the stockpile.

All samples are currently taken to Pantex for initial disassembly and inspection in preparation for either lab or flight testing. During this process a number of steps are taken which can include internal atmosphere sampling, safety switch radiography, and Permissive Action Links (PAL) checks along with some electrical resistance testing.

2.2.1. Laboratory Surveillance Testing

Laboratory System Testing is accomplished at the highest fuzing assembly level possible, and all fuzing modes are tested for each sample. During the initial fuzing mode test, one-shot devices associated with that mode are expended. For the remaining fuzing mode tests, electrical loads and external power supplies are employed. During system-level tests of bombs, tester-generated environmental sensing device signals are used to prearm the weapon. After all system-level testing is completed, the trajectory sensing devices are tested along with the firing set as a subsystem. Missile warheads generally have their system-level testing accomplished on a centrifuge which activates the trajectory sensing devices. Permissive action link and command disable testing is accomplished as a bench-level test for weapons so equipped. After all testing is complete, the reusable weapon components and parts are available for reacceptance and weapon rebuild.

The nuclear explosive package that is destructively examined is inspected and evaluated as specified by the nuclear design lab responsible for the weapon type. Measurements of the nuclear materials (such as radiography, density measurements, metallographs of welds and the base materials, acoustic measurements, eddy current measurements, etc) are taken of the particular parts, and chemical composition is analyzed for changes. Other materials, mostly plastics, are examined for effects of age and exposure to other materials in the environment. Explosive materials are evaluated on several of the samples for performance and for physical properties as well as for chemical changes in the binder or in the explosive.

2.2.2. Flight Surveillance Testing

Nuclear weapons are required to be capable of functioning with high reliability throughout their stockpile life over the full range of conditions in the Stockpile-to-Target Sequence. Joint flight tests are necessary to evaluate the weapon's flight characteristics and the operation of the non-nuclear components in operational flight environments throughout a weapon's stockpile life. These joint flight tests are planned and agreed to by the DoD and the DOE and involve resource and schedule commitments from both agencies. The data obtained from these tests are derived from measurements made in a realistic flight environment using a joint test assembly instead of a complete nuclear weapon. The data are used to complement and validate the larger database from component and subsystem production testing as well as laboratory stockpile evaluation programs. The data obtained should provide sufficient diagnostic information to investigate failures and to implement any necessary corrective actions.

For a flight test after the disassembly described above, the non-nuclear components are built into a Joint Test Assembly (JTA). In the place of the nuclear explosive, a data recording package is positioned to simulate the weight, center of gravity, and moments of inertia of the stockpile weapon. Since a Joint Test Assembly looks and responds like a real nuclear weapon, a non-nuclear verification program ensures that a war reserve weapon is not flown in place of a Joint Test Assembly. The assembly is then delivered in one of the specified delivery profiles for that weapon system. Some flight tests are conducted in which some parts of the nuclear explosive package are actually flown and other parts are simulated. These high-fidelity flight tests are the only means for Los Alamos or Lawrence Livermore to get flight test data directly on the nuclear explosive package.

2.2.3. Surveillance Reporting

The results of all of the surveillance tests and evaluation are summarized in a cycle report for each weapon type. A cycle is a period of testing usually covering a year. In the cycle report the tests done during that cycle are listed, the results from evaluation of the nuclear material and the results of lab and flight testing are provided. Any defects or findings made during that cycle are described.

2.3. Reliability Assessment

The assessment of weapon reliability begins during weapon development when a model is developed representing the weapon from a functional standpoint. Reliability estimates are made for the elements of this model as development tests proceed and utilizing data from similar components in weapons already in the stockpile. As mentioned above, there is no way to obtain enough data on the nuclear performance to establish a reliability estimate. Thus once the design of the nuclear explosive package is certified, the reliability is considered to be 1.0 from that time on. The reliability of the non-nuclear components is established for stockpile entry by means of environmental and destructive testing data collected during production. The reliability of the weapon is periodically reviewed.

The reliability of each mode of operation for the weapon is assessed. The reliability for non-nuclear components is based on production data, data from the Stockpile Evaluation Program, and any additional component tests required for the assessment. Not all data that are collected are pertinent for every mode of operation, so the reliability assessment is not a simple statistical calculation. Technical judgment is necessary to determine which data are to be included for the various assessments. The Department of Energy publishes a bi-annual weapons reliability report which provides a summary of the reliability assessment of each weapon in the stockpile.

3. DATA

3.1. All Weapons Since 1958

3.1.1. Defects and "Actionable" Findings

There have been 49 sealed pit weapon types in the stockpile counting the B61 as two weapon types — one with Conventional High Explosive in the primary, and one with Insensitive High Explosive in the primary. (This division is most relevant for the nuclear components, but not as clear-cut for the non-nuclear components in the B61 family. There are significant differences in the non-nuclear components for some of the different versions of the B61. However, for the purposes of this paper this division will suffice.) The weapon types are: W25, B27, W27, B28, W28, W30, W31, W34, B36 Mod 2, W38, B39, W39, W40, B41, B43, W44, W45, W47, W48, W49, W50, W52, B53, W53, B54, W54, W55, W56, B57, W58, W59, B61(CHE), B61(IHE), W62, W66, W68, W69, W70, W71, W72, W76, W78, W79, W80, B83, W84, W85, W87, and W88. The Stockpile Evaluation Program has covered 44 of these sealed-pit weapons types. (The B27, W27, B36 Mod2, B39 and the W39 entered the stockpile prior to the inception of the Stockpile Evaluation Program in 1958 and were never included in the program.) The Stockpile Evaluation Program also covered the W33 artillery shell which was not a sealed-pit weapon. Thus approximately 70,000 weapons from 45 weapon types have been covered by the Stockpile Evaluation Program. Over 13,800 weapons have been randomly sampled and tested through this program. The Department of Energy maintains a database of all the findings (defects and anomalous occurrences) encountered through the evaluation program and the other activities associated with nuclear weapons. This database contains more than 2,400 findings including repeat occurrences of the same finding. Excluding multiple occurrences, there are approximately 800 distinct findings. During the course of this study, about 30 additional findings concerning the nuclear explosive package were discovered which have not yet been added to the database. (As older data continue to be reviewed additional findings could be identified.) These findings were associated with weapon types which entered the stockpile during the late 1950s and early 1960s, some of which remained in the stockpile into the 1990s. More complete information is being sought for the inclusion of these findings in the database. However, these findings are included in each of the figures in this report. Figure 4 displays the activity area in which each of the unique findings was first discovered. The Stockpile Evaluation Program has found 75% of these occurrences.

Although a finding will not always result in an action taken to stockpiled weapons, a thorough investigation is conducted to understand the nature, cause, and consequences of the finding. These Significant Finding Investigations have been formally documented since the mid 1980s when the number of stockpile samples was reduced to 11 per year. The investigations often involve expertise from many disciplines across the DOE labs including materials, chemistry, physics, manufacturing, computational analysis, etc. At the close of the investigation, actions may be recommended and a reporting of the impact of the finding on the weapon reliability is made.

There have been ~400 "actionable" findings (including those findings for the nuclear explosive package not yet incorporated into the database) where an "actionable" finding is defined as one that resulted in a corrective action (not necessarily a change to the weapon, but sometimes a change to the procedure causing the problem) or a decrement to the weapon reliability. These "actionable" findings, along with the findings that were investigated without any action, are shown in Figure 5 by component category. Of the 50 weapon types considered in this report, 46 have had at least one finding and one "actionable" finding. Every component type has had a finding, and almost every weapon component type has had an "actionable" finding.

Figure 6 indicates the time after First Production Unit (FPU) at which the "actionable" findings occurred. For this figure the number of "actionable" findings has not been normalized to the number of weapon systems in the stockpile nor to the number of units tested. For example, all 45 weapon types covered by the Stockpile Evaluation Program were in the stockpile at year one after the first production unit, but only 11 of these weapon types remained at year 27. As can be seen, most "actionable" findings were found early in a weapon's life, largely as a result of new production sampling. Weapon production generally spans five to eight years after FPU, and there are many efficiencies to be gained by identifying problems (primarily design, fabrication, and production problems) while the weapon is in production and before very many weapons are produced. The new material portion of the evaluation program has, therefore, been weighted with more samples in the first six months of production in order to find potential problems as early in production as possible. "Actionable" findings which have resulted from a material degradation are labeled as aging findings in Figure 6. The data show that material problems are encountered, investigated and resolved throughout the lifetime of weapon in the stockpile. Finally, it is important to remember that although the number of "actionable" findings has diminished with time, any single finding can significantly affect the stockpile. For example, the two findings indicated by the arrows in Figure 6 impacted more than 3,000 weapons each. It is noteworthy that several weapon types are now being more actively monitored because of observed chemical changes in materials and components of the nuclear explosive package.

The profile of the number of weapon units evaluated through the Stockpile Evaluation Program by year post-FPU is depicted in Figure 7. Note that out of the more than 13,800 weapons evaluated, only 15 have been from weapon types 30 or more years beyond FPU. There is very little data upon which to base prediction of performance or reliability beyond 30 years. Also indicated on this figure are the current (1995) range of weapon ages for each type of weapon in the stockpile. This provides an indication of where the stockpile is today relative to the amount of experience from stockpile evaluation testing of previous stockpiled weapons.

The weapon types in the planned stockpile are likely to remain in the stockpile for much longer than originally anticipated. It is reasonable to expect an increase in the number of "actionable" findings due to aging of materials in these weapons. Thus the rate of "actionable" findings related to aging problems found to date is important to investigate. One way of determining this rate (shown in Figure 8) is to consider the number of aging findings each year per number of weapons tested each year through the Stockpile Evaluation Program. The trend of aging problems of most interest for the planned stockpile is that beyond the originally expected life of these weapon types, which is about 20 years. To provide a sense of trend, Figure 8 begins at 10 years beyond stockpile entry (FPU). The data for "actionable" aging findings and the data for the number of weapon units tested have been smoothed by using a running three year average. This smoothing has been done to help visualize the trend. (The unsmoothed rate goes to zero for years when no age related "actionable" finding was discovered and it is difficult to visually integrate those points when looking for a trend.) In addition to the estimated rate shown in Figure 8, upper and lower 90% confidence bounds have been added. These bounds show the range of potential rates which would be expected to include the true rate 90% of the time based on the number of weapon units tested. The estimated rate does not show much of a trend; even with the smoothing applied the data is somewhat scattered. However, a definite trend can be seen in the uncertainty bounds. The area between the upper and lower 90% confidence interval increases significantly beyond about 25 years after stockpile entry. The growth in these bounds reflects the small number of weapon units tested in those years. Despite the fact that some older weapon types have remained in the stockpile for longer than originally anticipated, not many of these weapons have been sampled for testing and evaluation and therefore the rate of finding age-related problems cannot be very confidently assessed from this data. An additional factor (not reflected in Figure 8) which adds to this uncertainty is the difference in technology between the planned stockpile and those weapon types which have had long lives in the stockpile (weapons designed in the late 1950s and early 1960s). Given the expectation that problems will increase as the stockpile ages beyond its originally anticipated lifetime, the amount of uncertainty in the future rate of discovering aging problems based on the data in hand, and the reduction in the production capacity which would be called upon to make changes as a result of "actionable" aging findings, it is incumbent upon the DOE to adopt a more comprehensive and predictive surveillance program as recommended in Section 4 of this paper.

Of the "actionable" findings, about one in three have resulted in a retrofit or major design change as shown in Figure 9. (This does not necessarily imply there have been ~120 retrofits and major design changes. There are occasions when a single retrofit will fix more than one "actionable" finding.) These retrofits and design changes impacted the entire build or a large fraction of it for 33 weapon types. About 25% of the "actionable" findings resulted in a change in production processes, and about 45% were handled by accepting a lowered weapon reliability, by changing product test equipment that was introducing the problem or by changing some specification concerning the weapon to accommodate the finding (no physical change to stockpiled weapons resulted from these cases).

Table I provides a summary of the findings and "actionable" findings since 1958. The number of findings for non-nuclear components is much larger than that for nuclear components in a large part due to the fact that there are so many more non-nuclear components in a nuclear weapon and that the non-nuclear components are tested more frequently. However, the ratio of those findings that require some action to the total number of findings is greater for the nuclear components. Thus when a finding has occurred for a nuclear component, it has generally been a serious one requiring action to correct. Often these corrective actions to nuclear components have required changes to all of the weapons comprising the weapon type affected.

Table I. Summary of findings since 1958.

	Number of Findings	Number of "Actionable" Findings	Number of Weapon Types with "Actionable" Findings
Primary (includes warhead detonators)	127	97	34
Secondary (including radiation case, nuclear assembly, and other components)	18	13	8
Non-nuclear Components	703	306	38

The data for the nuclear explosive package included in this report show that there were approximately 110 cases on 39 weapon types requiring some remediation either to the entire build of that design or to all weapons produced after the particular finding. In addition to rebuilds and changes in production procedures, other actions to the nuclear explosive package included imposing STS restrictions on the weapon; accepting a reliability decrement or a safety risk (related to designs that were considered marginally not one-point safe during the evolution of one-point safety criteria in the late 1950s and early 1960s); and in several cases the execution of a nuclear test to determine that the finding did not require any physical change. There have been other instances not counted as "actionable" where a material was chemically changing and the weapon was closely monitored to see if further action was necessary or where the occurrence was determined to be an isolated case that did not require remediation.

3.1.2. Changes Made

A Product Change Proposal documents any change that could affect the safety, reliability, operating, or maintenance procedures for a weapon. Signature approval must be obtained from the design lab(s) involved, DOE Albuquerque, and FCDNA (as a representative of the military service involved).

Since 1958 there have been about 400 change proposals approved involving sealed-pit weapons (Figure 10). There is no definitive reason for the abrupt drop in proposals in 1967. However, a number of reasons can be proposed for the intense activity between 1958 and the mid 1960s. There were 19 new weapon systems introduced into the stockpile between 1958 and 1963 including the first ICBM and SLBM strategic weapons and the first generation of sealed-pit weapons (see Figure 11 which shows only the strategic systems). Furthermore, it was during the nuclear test moratorium (1959-1961) that designers of the boosted primaries began to take advantage of new methods and physics models to study one-point safety of sealed-pit weapons in detail. The startling and grave results of these studies and of the hydronuclear experiments they prompted led to many changes in the stockpile. Finally, more nuclear tests were executed in the years immediately before and after the moratorium than at any other time in the 50 year history of the program (77 announced tests in 1958 and 98 in 1962).

Since 1967 an average of six change proposals have been approved each year, mostly concerning non-nuclear components and ancillary equipment. Excluding the relatively minor changes involving ancillary equipment and tritium conservation, there have been 210 "major" changes to fix safety, reliability, or performance problems since 1958 (Figure 12). Again there was a surge of activity prior to 1967, after which there has been an average of about three changes approved per year. (The increase in changes during the 1992 to 1993 time frame was in preparation for transporting tactical weapons from Europe to the US for disassembly in accordance with treaty agreements).

3.2. Planned Stockpile

For this study the planned stockpile refers to weapon types expected to be in the stockpile in the year 2000. These weapon types are: B61 (Mods 3, 4, 7 and 10), W62, W76, W78, W80 (Mods 0 and 1), B83 (Mods 0 and 1), W84, W87, and W88.[3] Table II shows the First Production Unit (FPU) dates for each of these weapons and the length of their production.

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[3] A modification of the B61 is expected to replace the B53. The B61-7 data can be used to represent this weapon.

Table II. Year of First Production Unit (FPU) and length of production for each weapon type in the planned stockpile.

Weapon Type	*FPU Year*	*Length of Production*
B61-3	1979	12 years
B61-4	1979	12 years
B61-7+	1985	6 years
B61-10	1990*	2 years
W62	1970	7 years
W76	1978	10 years
W78	1979	4 years
W80-0,1	1981**	10 years
B83-0,1	1983***	8 years
W84	1983	6 years
W87	1986	4 years
W88	1988	3 years

+Some components in the B61-1 were not replaced during the production of the B61-7 and are approaching 30 years of age.
*The B61-10 production reused some W85 parts as well as new production parts.
**The W80 production was halted for about one year soon after FPU to resolve an "actionable" finding. The first W80 units reached the stockpile in 1982.
***This represents B83-0 production and not the conversion of some B83-0s to B83-1s.

3.2.1. Defects and "Actionable" Findings

Figure 13 indicates the number of findings that have been discovered for these weapons by weapon type. The B61-Mod-3, 4, and 10 have been combined because they are nearly identical weapon types. Also indicated on this chart are the number of years since FPU in 1994 for each weapon type. (The B61-3, 4, and 10 number reflects the B61-3, 4. It is not clear how many years to associate with the B61-10 since some of its parts were newly produced beginning in 1990 and some of its parts were in the stockpile in W85 weapons.) There have been over 150 findings for these weapons since their stockpile entry beginning in 1970 with the W62. As before when all of the weapon types since 1958 were being discussed, not all of the findings made for the weapon types of the planned stockpile have required action. In Figure 14 the "actionable" findings along with those findings that were investigated with no action are broken into their component categories. The data on "actionable" findings for the planned stockpile must be viewed with the perspective of the rest of the stockpile history. The fact that an "actionable" finding has not been discovered for some component category for the planned stockpile does not rule out problems in that category in the future. The Department of Energy must remain vigilant over all the components in the planned stockpile and have the necessary expertise to resolve any finding that occurs in the future.

The time of discovery of "actionable" findings for the planned stockpile (Figure 15) follows a trend similar to that of the rest of the stockpile (Figure 6). The rate of "actionable" findings is consistently higher for the planned stockpile perhaps because these weapons are more complex and/or the experience gained from 35 years of surveillance has allowed earlier detection of potential problems. However, the trend of an initial decline of findings with time holds for the planned stockpile as it did previously for the entire stockpile. As mentioned in the discussion of Figure 6, caution must be used when considering the applicability of the trends in Figure 6 to the planned stockpile. The experience with older weapon types may not be relevant to the planned stockpile due to the use of different components, materials, and production processes. "Actionable" findings have resulted in retrofits and major design changes for the planned stockpile at about the same rate as for the historical stockpile (Figure 16). However on a percentage basis, more changes have been made to the processes (production and field) for the planned stockpile. This may be the result of rather long production times for a number of the planned weapon types providing many opportunities for changes in weapon production processes.

3.2.2. Changes Made

Figure 17 shows the major changes made to the planned stockpile by weapon type. Over three fourths of the major changes made to these weapons have been to restore reliability.

The rate of implementing change proposals for the planned weapons is within the range that would be expected from the historical record of the last 20 years. Although the rate of "actionable" findings is higher for the planned stockpile, it is similar enough to the historical "actionable" findings data to allow the use of the historical data to make some rough projections of the future workload for "actionable" findings and weapon changes. The best projections of the future health of a weapon type are not based on the past history of that weapon but on the history of other weapon types in the stockpile that have had similar aging. Therefore, based on the age of the planned stockpile over the next ten years, historical data would project an average of one to two "actionable" finding per year in the planned stockpile and an average of one to two change proposals approved per year, with one of these resulting in a major change. These projections are most likely minimum numbers. The stockpile they were derived from was on average younger than the planned stockpile will be in future years, and the number of components in the weapon types were fewer than the number of components in weapon types of the planned stockpile. Furthermore, the planned stockpile contains different materials from the stockpile of the past, and the aging characteristics of some of these materials are not well understood.

4. RECOMMENDATIONS

4.1. Future Methods of Assessment

The previous section describes how problems were identified in deployed warheads during the period when nuclear testing and active weapon development were being conducted along with the stockpile surveillance and evaluation process. At the present time, with no anticipated new warheads and no nuclear testing and a much reduced production capacity, new approaches are needed to assess warheads for potential problems and anticipate aging concerns, especially in the physics package. In announcing the nuclear test moratorium in July of 1993, the President acknowledged the need for new methods to assure confidence in the stockpile:

"To assure that our nuclear deterrent remains unquestioned under a test ban, we will explore other means of maintaining our confidence in the safety, reliability, and performance of our own weapons."

The Department of Energy believes that we will be able to maintain that confidence through the Stockpile Stewardship and Stockpile Management Programs which will provide the "other means" as mentioned by the President. These programs are critical to maintaining confidence in the safety and reliability of the stockpile, especially since the smaller, less diverse US stockpile of the future will be more vulnerable to single-component and common-cause failures (i.e., failures or defects compromising the safety or reliability of, respectively, a single weapon system or several systems sharing a common design feature).

The Stockpile Management Program will continue to rely on well-established surveillance and evaluation methods while the Stockpile Stewardship Program develops new methods for addressing aging and performance issues. As the new methods mature for either nuclear or non-nuclear components, they will be incorporated into the surveillance program. The thrust of this approach is to augment the program that is already in place and enhance our scientific base to improve our understanding of how weapons age in the stockpile.

In the future, for example, we will rely on improved aboveground experimental capabilities coupled with an improved computational capability to address issues associated with primaries and secondaries. These experimental capabilities, along with an enhanced Stockpile Surveillance Program, are now crucial to help assess the current state of the stockpile and to provide long lead time information about incipient problems.

The reduction of production capacity has significant implications for the approach taken toward stockpile surveillance and evaluation. In the future, the workload in the production complex must be carefully managed to remain within budgetary and facility constraints. Therefore, one important goal of the surveillance and evaluation program must be to become more predictive. In the past, problems were addressed as they appeared. In the future, problems must be anticipated to the greatest extent possible[4] so that corrective actions can be planned and scheduled in the production workload before a significant impact on weapon reliability occurs. This approach requires an understanding of aging phenomena and computational modeling to project the impact of such aging phenomena on weapon reliability, performance, and safety. Research in these areas is being pursued both for nuclear and non-nuclear components.

The Department of Energy is also developing two new processes that will be integral to future assessment methodologies: dual revalidation and requalification. Dual revalidation with independent technical review is an assessment of a weapon using current analytical and computational tools to determine if a weapon conforms to its requirements. It is being developed in conjunction with the DoD. Previous nuclear tests, above ground experiments, and surveillance data will be considered in this process. Requalification is a formal program to certify that components older than their intended life will continue to their performance and safety requirements.

4.1.1. Hydrodynamic Experiments

Hydrodynamic testing will be our principal remaining tool for evaluating performance of stockpile primaries. Hydrodynamic experiments will aid in our understanding of high explosive (HE) aging, detonator aging, and the impact of chemical reactions and interface changes. These experiments will be used to assess the implications of results from surveillance and laboratory testing, which will include careful monitoring of plutonium metallurgy and extensive testing of HE properties from sampled primaries. Results of hydrodynamic tests using aged components where possible will be compared with baseline hydrodynamic data that has been correlated to the confirmatory underground nuclear experiment. These comparisons will form the basis of integral performance assessments.

To satisfy the near-term need for better hydrodynamic data to help assess primary performance and safety, the Dual-Axis Radiographic Hydro test facility (DARHT) at Los Alamos and LLNL's Flash X-Ray facility (FXR) upgrade at Site 300 would be used in conjunction with improved diagnostic tools such as the gamma-ray camera. These facilities, although they represent the current state-of-the-art, are limited by the radiographic energy, the number of photographic exposures, and orientation of exposures for each experiment. An Advanced Hydrotest Facility (AHF), under consideration but not

[4] Note that defects which were unexpected will most likely continue to appear. The approach suggested aims to reduce the number of surprises with the understanding that complete elimination is probably not attainable.

proposed, would provide significant new capabilities by providing up to eight radiographic views (compared to the two views that would be provided by the Dual-Axis Radiographic Hydrotest facility or the two time exposures at the Flash X-Ray facility). Such multi-view, multi-time radiography may be essential for assuring weapon reliability and safety without nuclear testing in the long term. An Advanced Hydrotest Facility would provide multiple images (20 or more) that would reveal the evolution of a primary's implosion symmetry and boost-cavity shape under normal conditions and in accident scenarios.

4.1.2. Advanced Non-destructive Surveillance with Neutrons

Neutron scattering is one of the best scientific tools available to advance our detailed knowledge of the aging process in nuclear weapons. For more than 40 years neutron scattering has played a major role in studies of condensed matter. Neutron diffraction, as a tool for material structural investigation at the atomic level, will be applied to study aging processes at the Los Alamos Neutron Science Center (LANSCE). Aging of plutonium will be addressed using phonon spectroscopy and neutron diffractometry which is also useful for residual strain measurements in non-nuclear components. High explosive aging effects can be assessed with resonance radiography, small-angle scattering, and photon spectroscopy.

Fast neutron radiography, a promising technique for assembled weapon surveillance, is able to detect imperfections on the scale of several millimeters in light materials hidden inside of heavy metal assemblies 30 to 50 times better than radiography with x-rays. Planned improvements at Los Alamos Neutron Science Center will produce neutron fluxes that allow the possibility for high resolution (of order one millimeter), three-dimensional tomographic reconstruction of the nuclear explosive package interior without disassembly and destruction of these high value components.

4.1.3. Laser and Pulsed Power Experiments

Laser and pulsed-power experiments can be useful in developing a better understanding of the details of aging processes. For primaries, pulsed power can provide a means of obtaining precision material data (ejecta, spall, and equations of state) on aged plutonium.

Understanding the effects of aging on secondaries is a much more difficult problem than for primaries because one cannot perform full-scale integrated experiments at secondary hydrodynamic conditions. Moreover, there is a significantly larger legacy of data for primaries from both hydrodynamic experiments and nuclear tests to help evaluate problems or suspected problems. Only recently have Nova experiments been conducted with direct application to secondaries of stockpile weapons. The National Ignition Facility (NIF)[5] and pulsed-power facilities such as Atlas would allow data to be collected pertinent to specific problems that occur in aging secondaries to provide a greatly enhanced capability for obtaining data pertinent to specific aging problems and potential corrective actions. The National Ignition Facility experiments would be in an energy density regime closer to a weapon, while Atlas experiments would be in a volume regime closer to a weapon.

However, the most important role of these new facilities would be in the development of more accurate computational physics models needed to reliably predict secondary performance. In the long run, the effects of aging or corrective actions on the full performance of a secondary can only be calculated.

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[5] The National Ignition Facility would also have some capability for experiments for the study of ignition and burning of DT gas.

4.1.4. Computations

The Accelerated Strategic Computing Initiative will provide the computational capability required to scale understanding gained from laboratory experiments to predict performance of a weapon. In addition, computations will be necessary to model aging phenomena and to make predictions on future performance, reliability, and safety for both nuclear and non-nuclear components.

4.1.5. Stockpile Evaluation Program: Laboratory and Flight Testing

The Stockpile Evaluation Program must evolve from one of looking for and fixing problems to one that not only continues to look for problems but also makes projections about when and where problems are going to arise and when these problems must be corrected before they become serious. In making this transition, the architecture of the program will change to allow acquisition of new kinds of data of a forensic nature for the nuclear design community.

Over the life of these weapons, it is recognized that significant statistical data for a meaningful calculation of performance reliability for nuclear components cannot be obtained through destructive testing. Furthermore, current destructive testing of non-nuclear components will draw the stockpile below operational requirements if replacement components are not available. While developing a more comprehensive understanding of the aging behavior through destructive tests, non-destructive test technologies will be developed. The goal is to elevate our predictive capability of component aging and performance problems by employing and correlating both destructive and non-destructive test technologies.

There is also a potential source of valuable aging information to be gleaned in the dismantlement of our older stockpiled weapons. These weapons can be an important source of some materials and components for testing and for verifying predictive models.

The current equipment used to do the system level lab testing for non-nuclear components is quite old. New test equipment is under development which is intended to be more cost effective. This equipment, along with new test procedures that will accompany it, will reduce the time required for test preparation, equipment calibration, test activity, and troubleshooting.

In one other departure from previous practice, the laboratories will do much of the analytical work on stockpile samples at their own facilities. (Previously, this analysis was done at production sites, many of which are now closed).

In the past the flight test program has served as a mechanism for electrical components and mechanical and electrical interfaces to be functioned in real flight environments having been launched from actual delivery platforms. The flight test programs now have an additional requirement to include a configuration that has a high-fidelity replication of the nuclear package and fuzing. These units maximize use of stockpile material from the parent stockpile weapon. High Fidelity Joint Test Assemblies will be developed for those weapon types which do not currently have a high fidelity version. Data collection systems need to be developed to gain information on performance of major subassemblies (like the primary or secondary) in flight. Dynamic ground test techniques are being developed and correlated to flight performance through concurrent testing and numerical analysis. These tests will provide the opportunity to obtain important data on flight performance of nuclear materials.

The surveillance of the stockpile may also be improved by the incorporation of sensors into the weapon to indicate when some of the anticipated aging problems are being manifested. Environmental sensors may be the first of these sensors to be implemented. There have been times in the past when an investigation of a problem would have been improved if the temperature cycle or the humidity the weapon had been exposed to was known. Such sensors might apply for both nuclear and non-nuclear components.

The methods described above all contribute to a principal objective: Provide the ability to predict with a longer lead time the onset of an aging problem such that remedial actions can occur with a schedule which will fit within the budget and facilities of the planned production capacity.

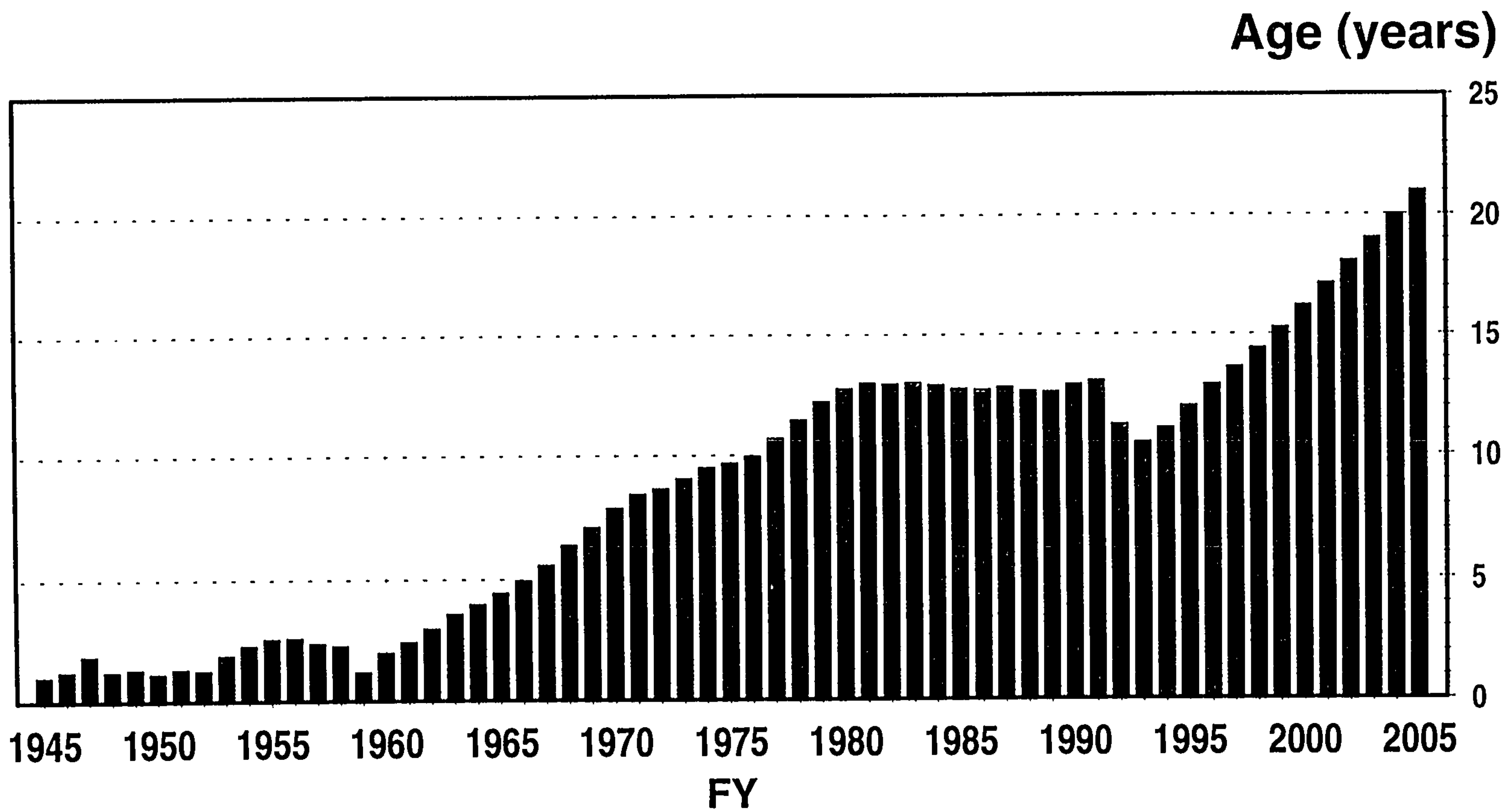
5. DATABASE RECOMMENDATIONS

The major recommendation addressing the database concerns linking this data to other data relevant to problems in the stockpile. The existing "Findings Database" is useful in understanding problems that have occurred in the past. However, the database is only a piece of a much larger set of information that will be important in the future. The descriptions of the problems, which are found in the database, are limited at best. Some of the problems were found through research activities and are documented in specific R&D reports. For those problems found through surveillance and stockpile activities, more complete descriptions are found in the cycle reports which summarize all of the Stockpile Evaluation Program test activity and results for each weapon type on an annual basis. The monthly Significant Findings Status Reports also provide better description of the problems. Often information relating to the production of components that develop problems is critical to understanding the nature of the problem. Record of assembly data, which accounts for the components in each nuclear weapon, is also valuable data. A relational data management system is needed to integrate all of this information. The technology is available to allow improved tracking and trend analysis for weapons in the stockpile. This approach will support knowledge preservation, make modeling and prediction more accurate, and provide more complete and efficient data access for the production complex.

Classified Appendices

Appendix A - Discussion of Underground Nuclear Testing
Appendix B - List of Los Alamos Findings and Issues Concerning the Current Stockpile Weapon Types
Appendix C - List of Lawrence Livermore Findings and Issues Concerning the Current Stockpile Weapon Types
Appendix D - List of Sandia Findings and Issues Concerning the Current Stockpile Weapon Types
Appendix E - List of Findings and Issues for Weapon Types Retired from the Stockpile
Appendix F - Listing of Findings and Changes in the Sandia Database
Appendix G - Listing of Findings Related to the Nuclear Explosive Package

Figure 1. Average age of the Stockpile* FY 1945 - 2004.



* "Stockpile" is the total stockpile; that is, all capsule systems, gun-type weapons, and sealed-pit systems. Derived from stockpile data in "A HISTORY OF THE NUCLEAR WEAPONS STOCKPILE (U), FY1945-FY1991" and P&PD 95-0.

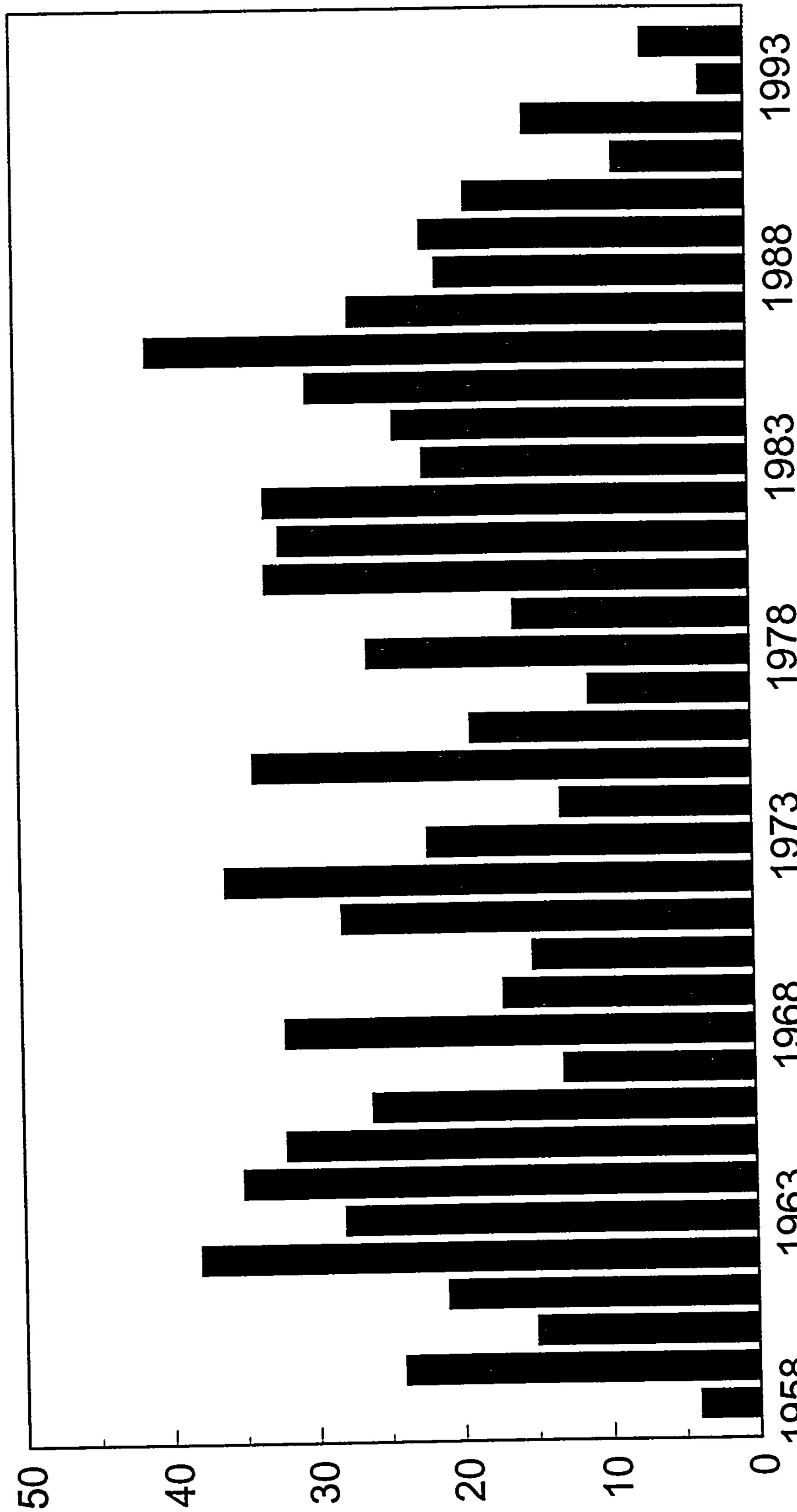


Figure 2. Number of findings per year since 1958.

Figure 3. Number of "actionable" findings per year since 1958.

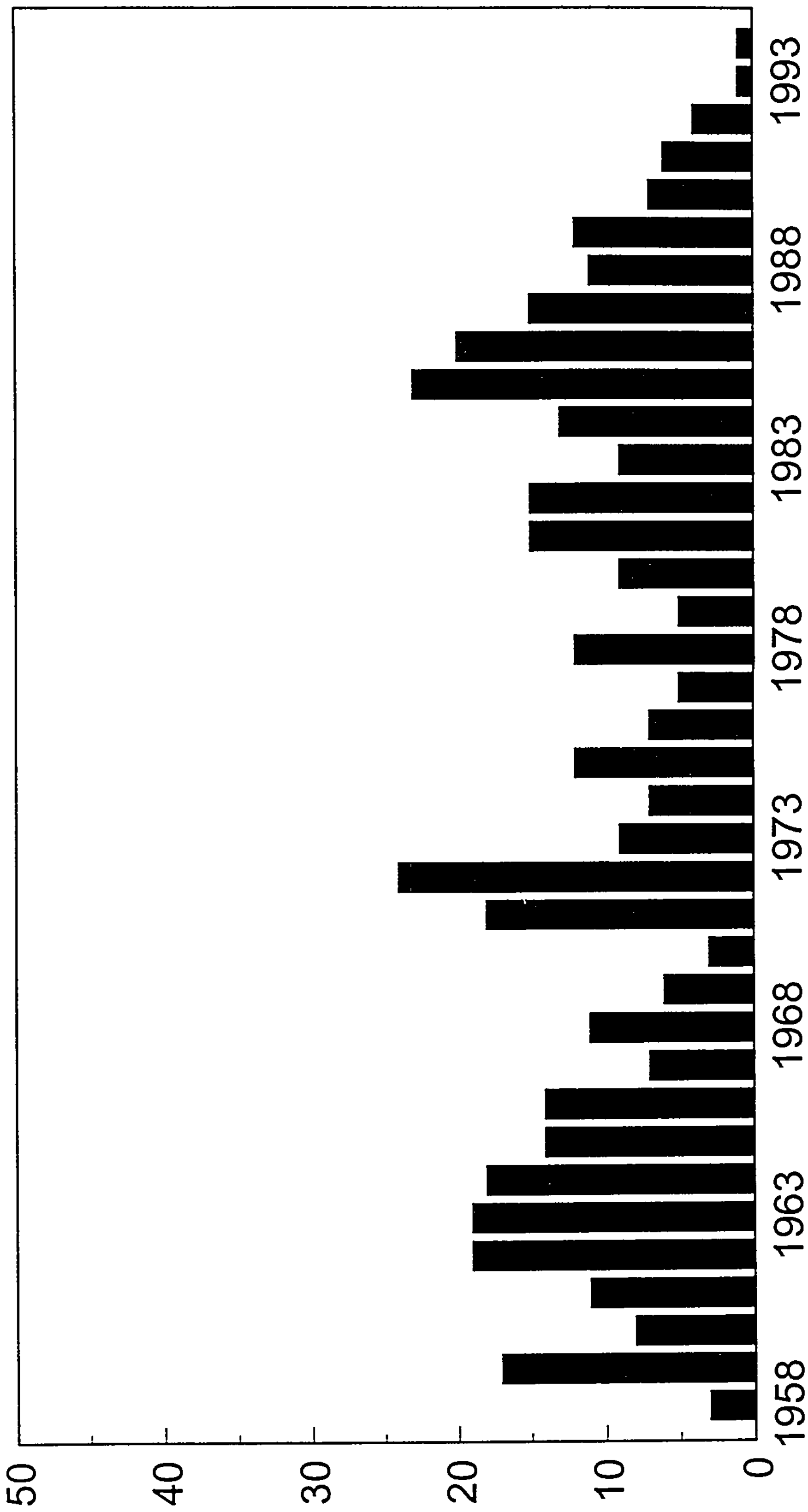
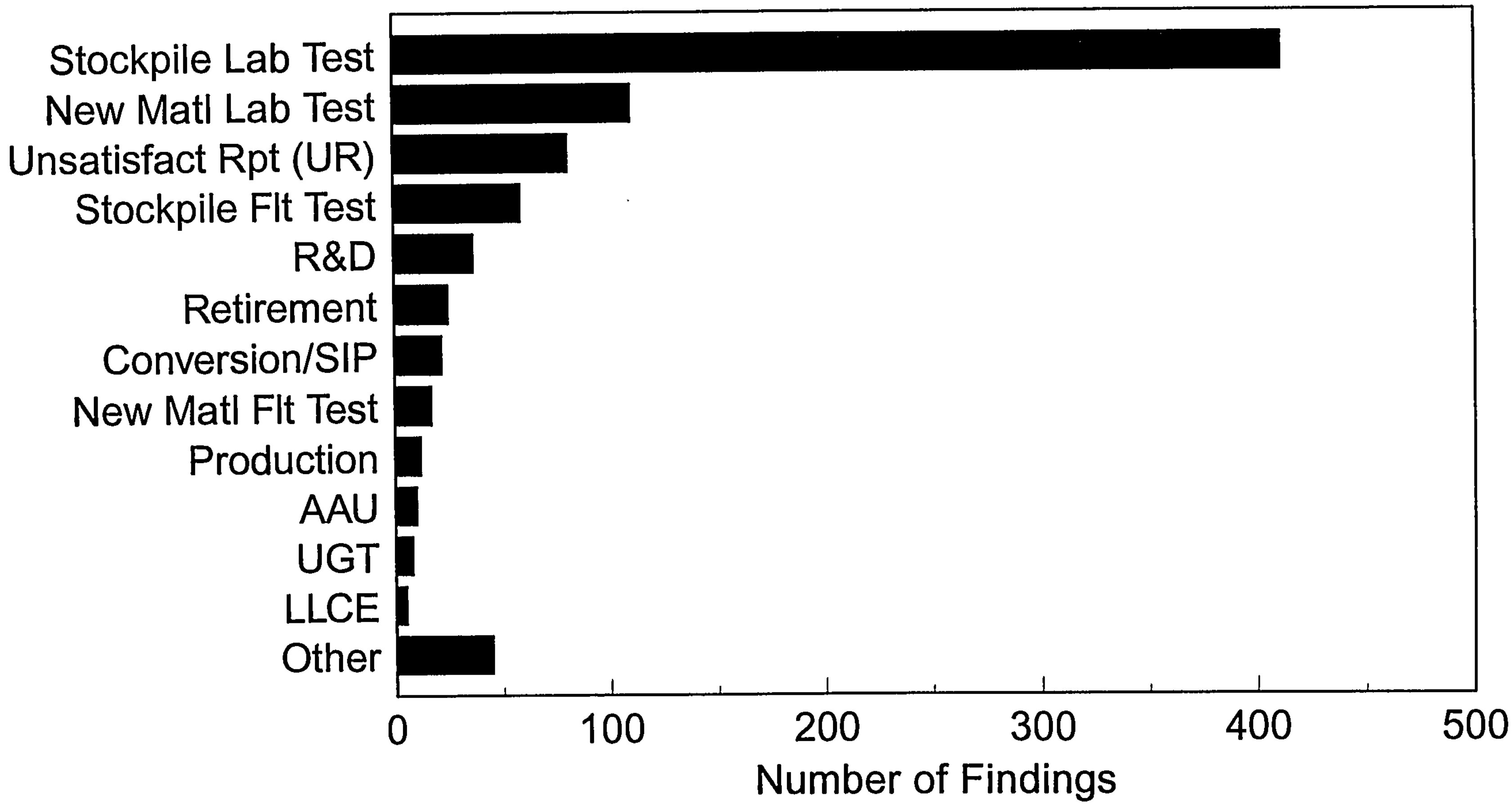
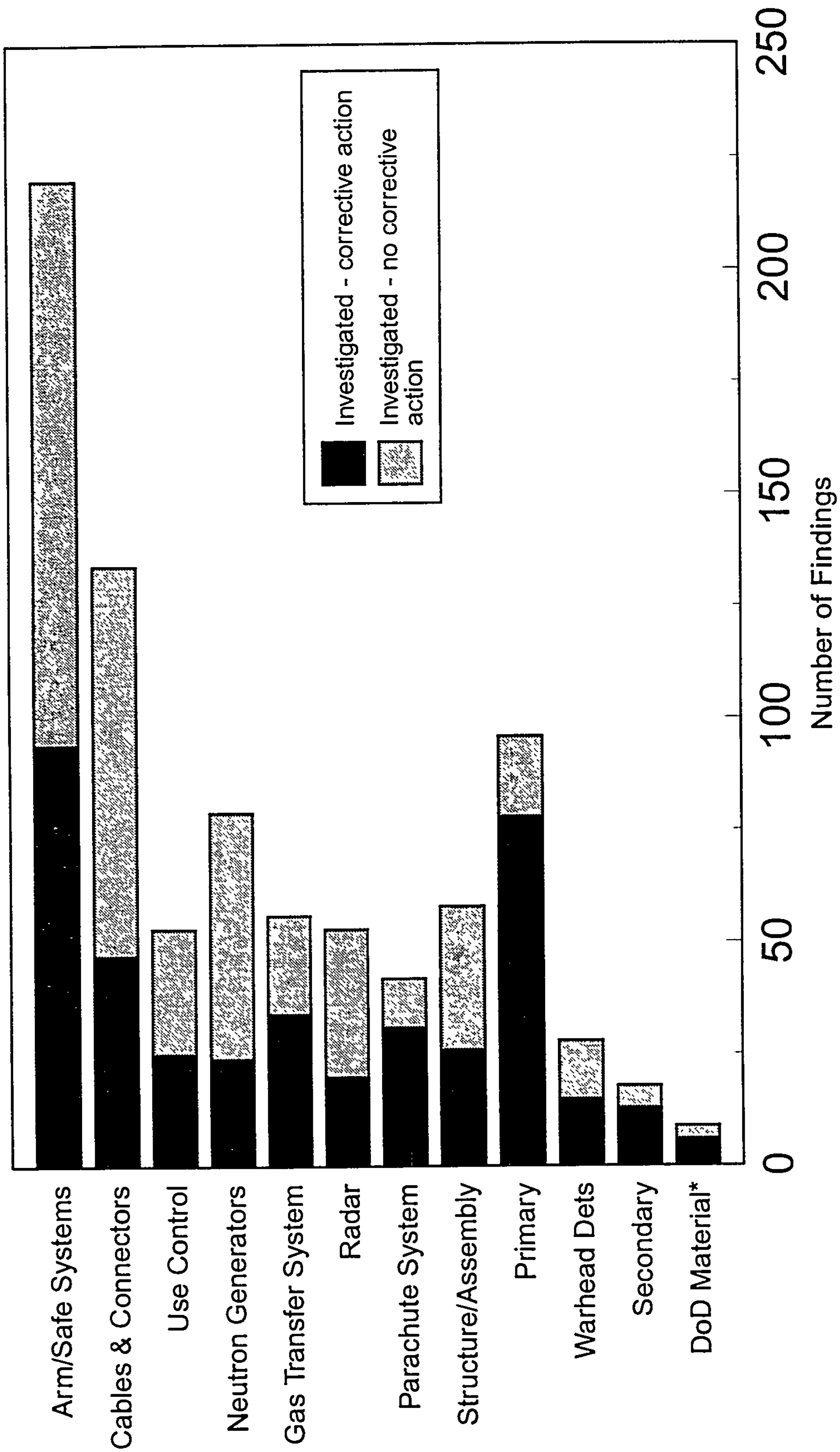


Figure 4. Activities where findings are first discovered. Approximately 75% have been found by the Stockpile Evaluation Program.



Unsatisfactory Report - Report made by the using military service concerning a discrepancy with a nuclear weapon or associated gear; SIP - Stockpile Improvement Program; R&D - Research and Development; AAU - Accelerated Aging Unit; UGT - Underground Test; LLCE - Limited Life Component Exchange

Figure 5. Findings by category type.



* DoD material refers to parachute problems prior to parachutes becoming Sandia responsibility, Army fuze findings and other DoD material findings uncovered in Stockpile Evaluation testing.

Figure 6. Year after First Production Unit (FPU) when "actionable" findings are discovered.

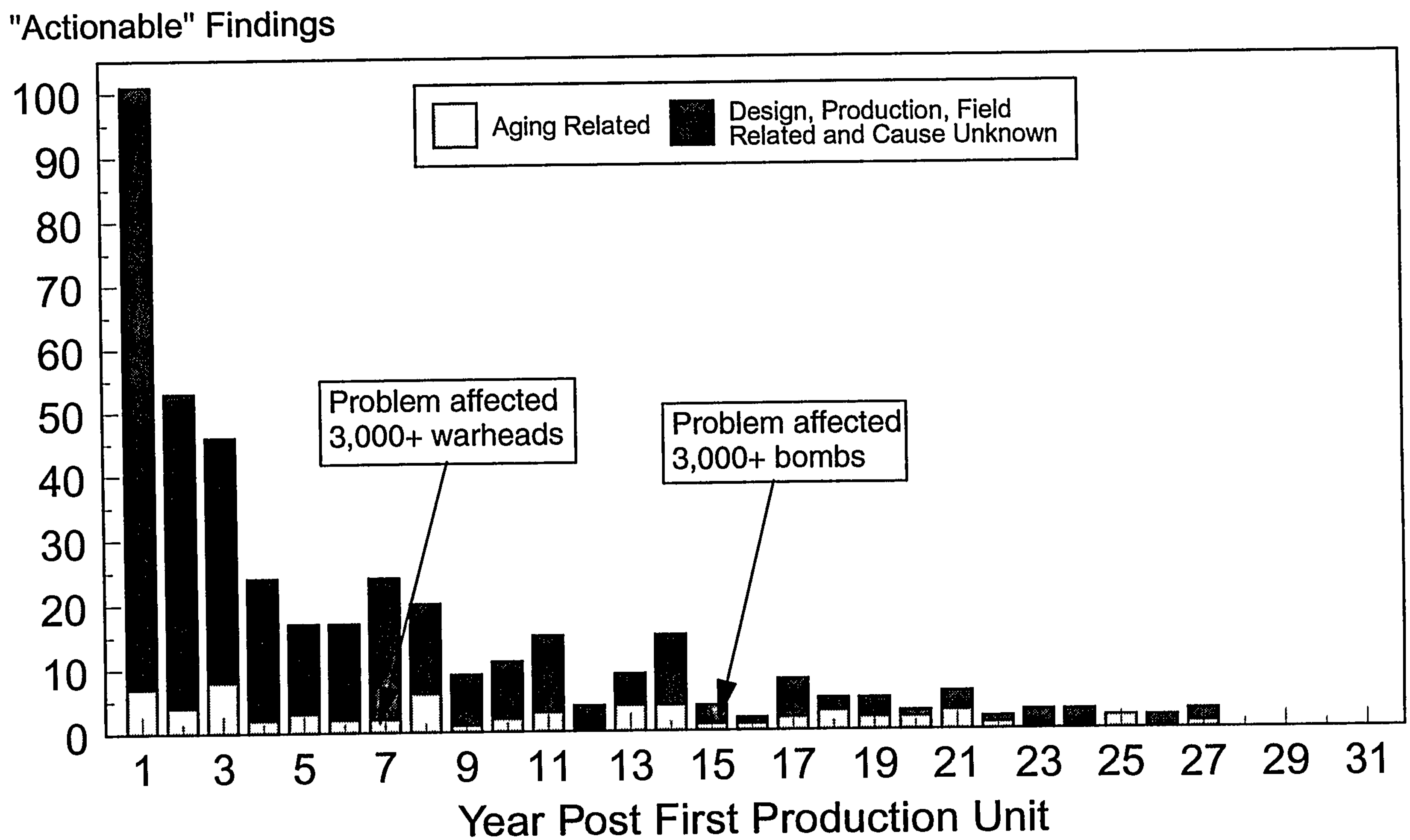


Figure 7. Number of weapon units tested per year past stockpile entry.

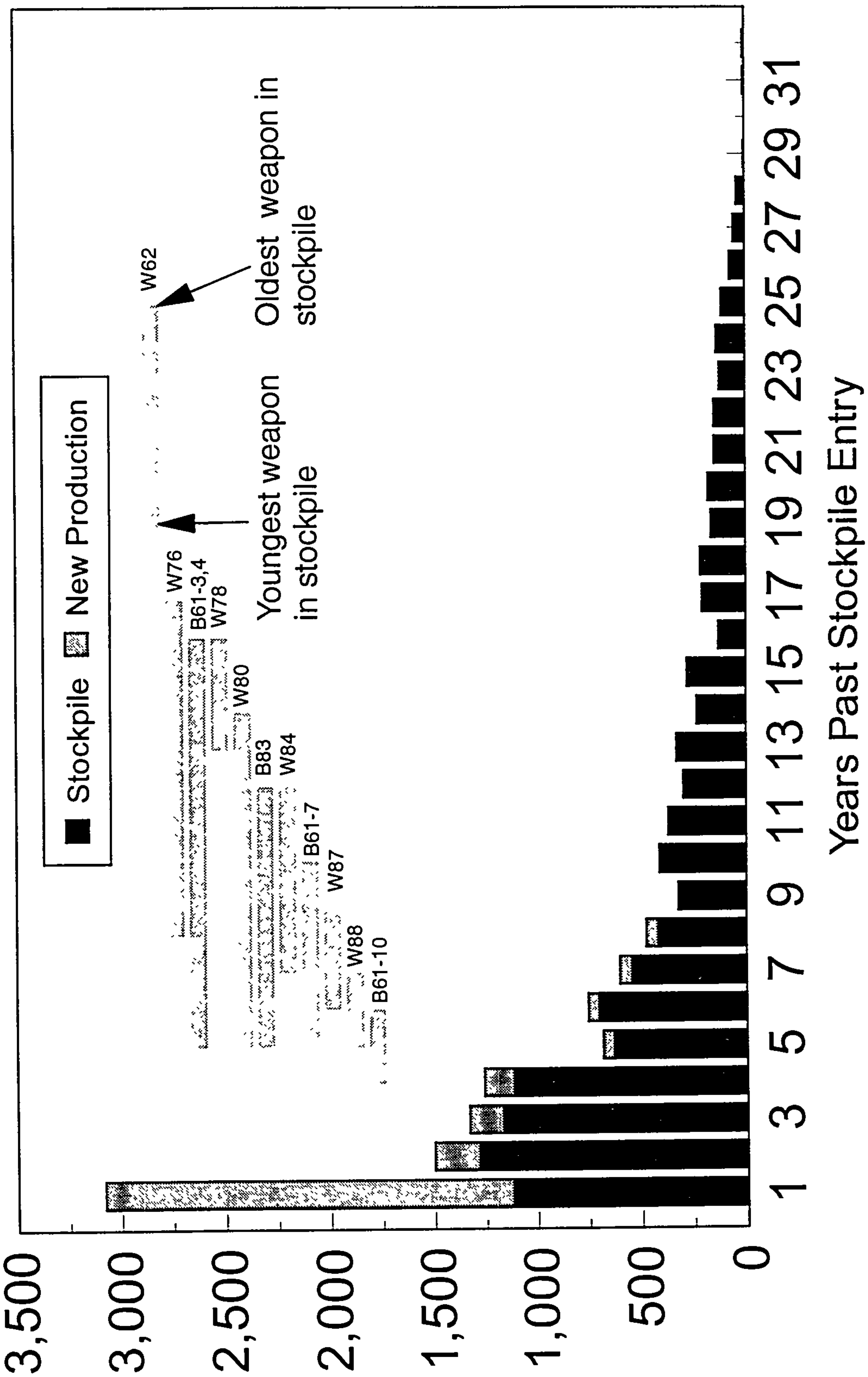
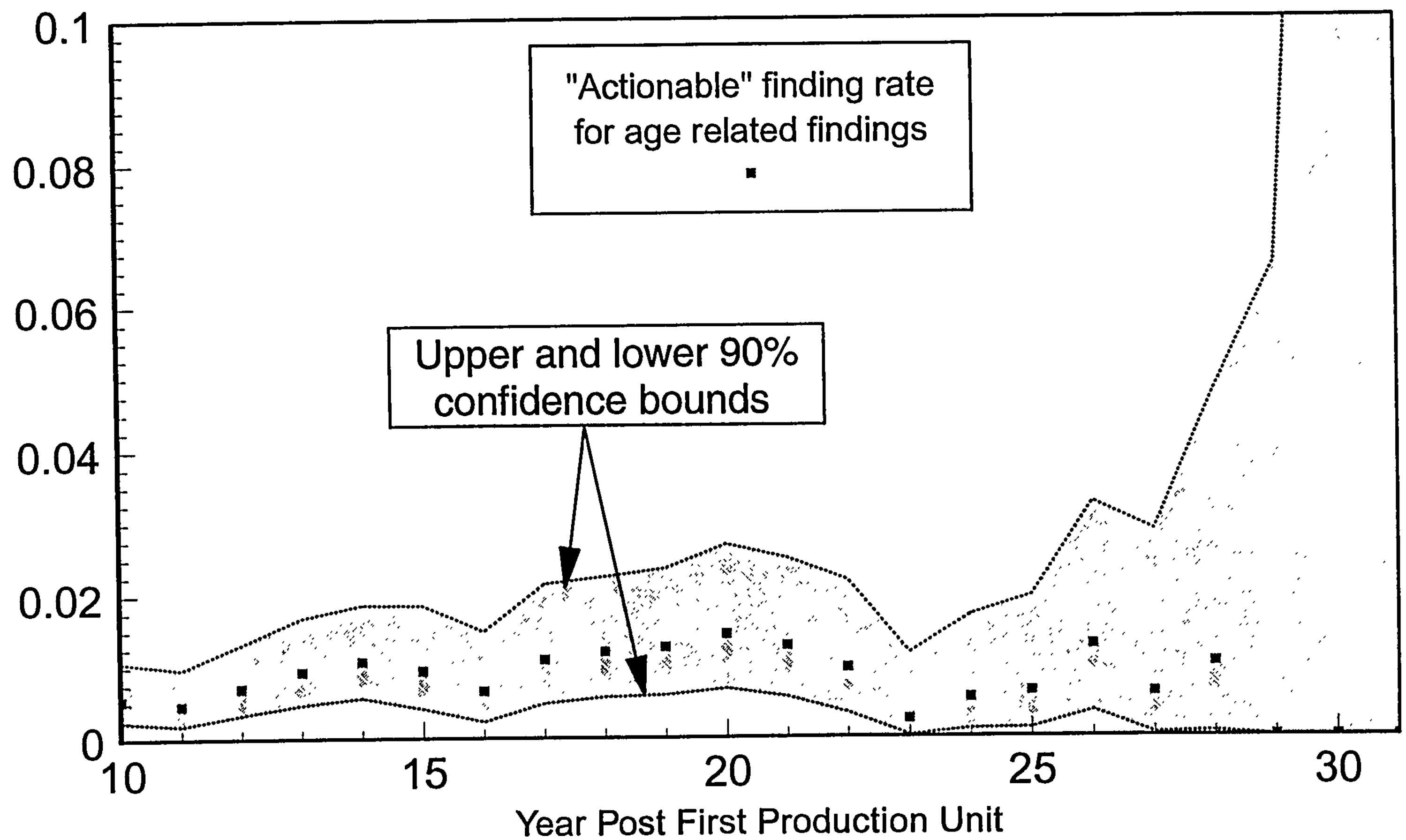


Figure 8. Normalized rate* of "actionable" aging findings with 90% confidence bounds.



* The normalized "actionable" aging finding rate is the number of aging related "actionable" findings each year per number of weapon units tested each year through the Stockpile Evaluation Program. The data for aging related "actionable" findings (small bars on Figure 6) and for the number of weapon units tested (data from Figure 7) has been smoothed using a running 3 year average ((yr[x-1] + yr[x] +yr[x+1])/3) to help visually accomodate for the scatter in the data, especially in the years when no "actionable" findings were discovered.

Figure 9. One In three of the "actionable" findings has been corrected by a retrofit or major design change.

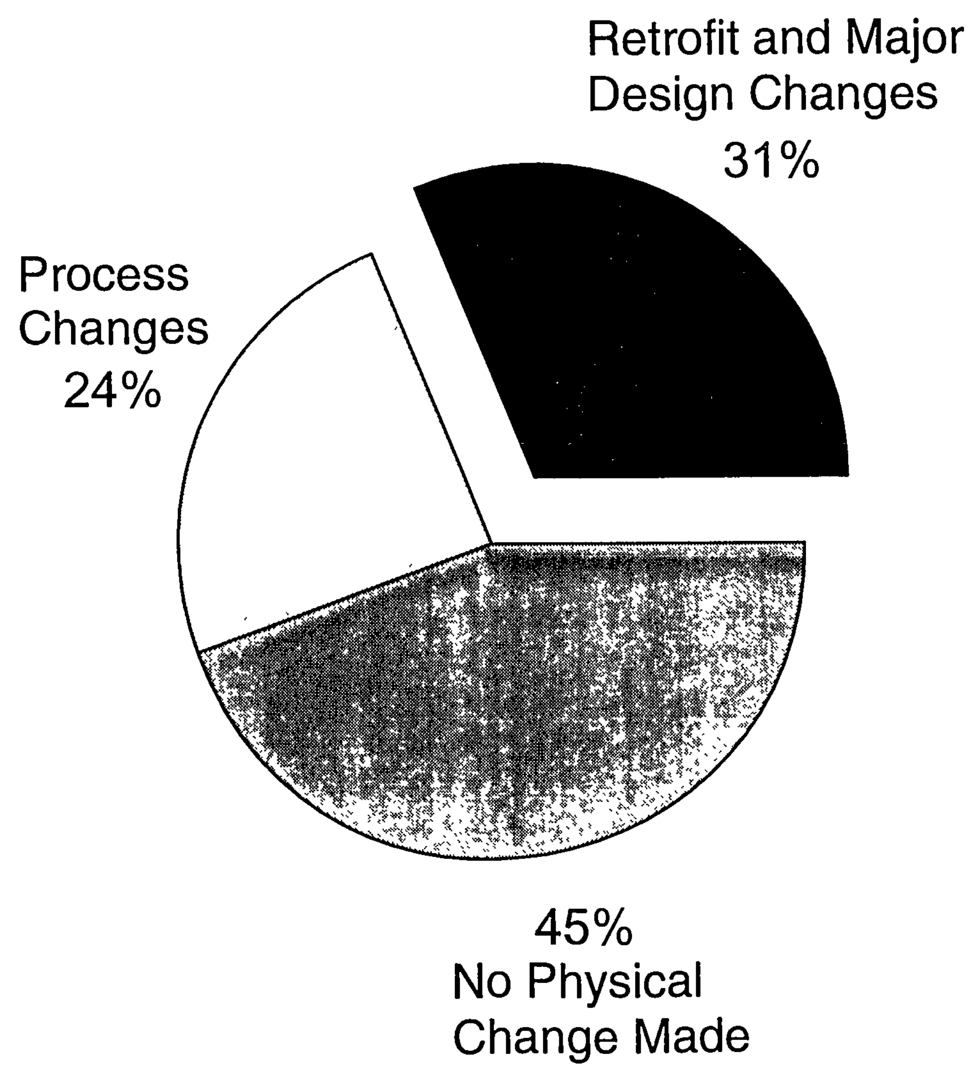
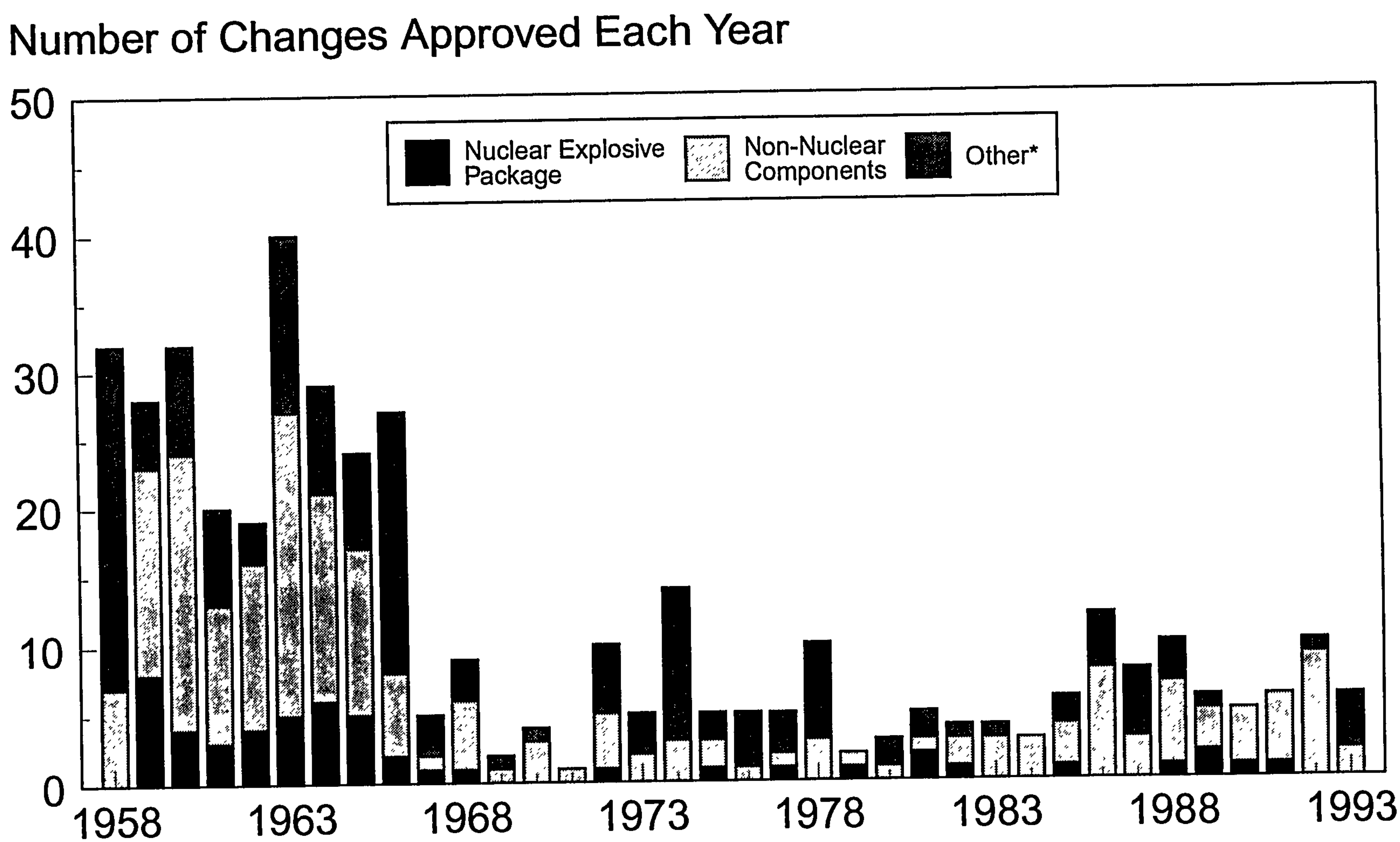


Figure 10. Since 1958, 400 changes have been approved for sealed-pit weapons.



* Other includes Handling, Training, Testing gear, weapon assembly and weapon identification markings.

Figure 11. Cycle of development for strategic systems in the stockpile.

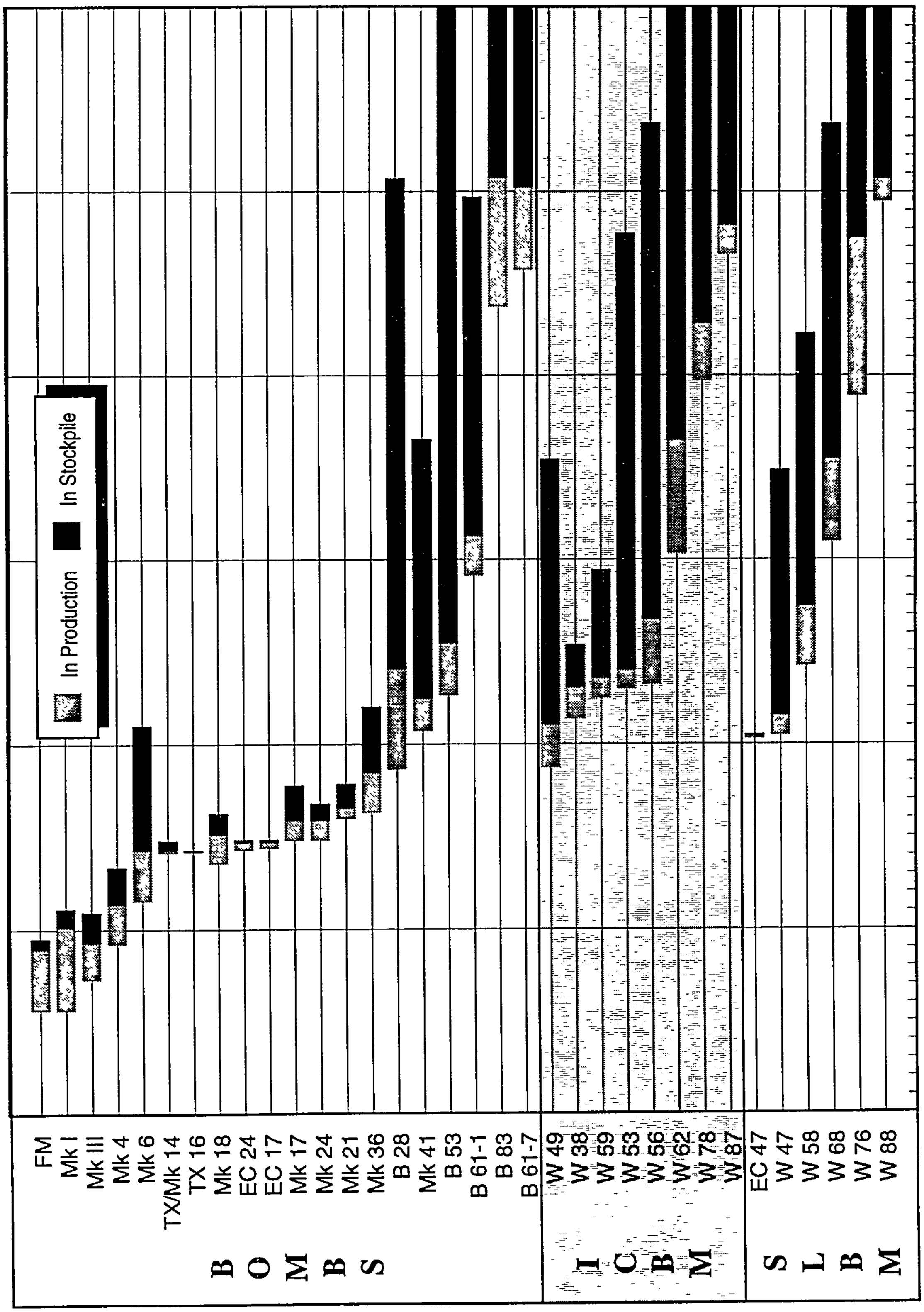
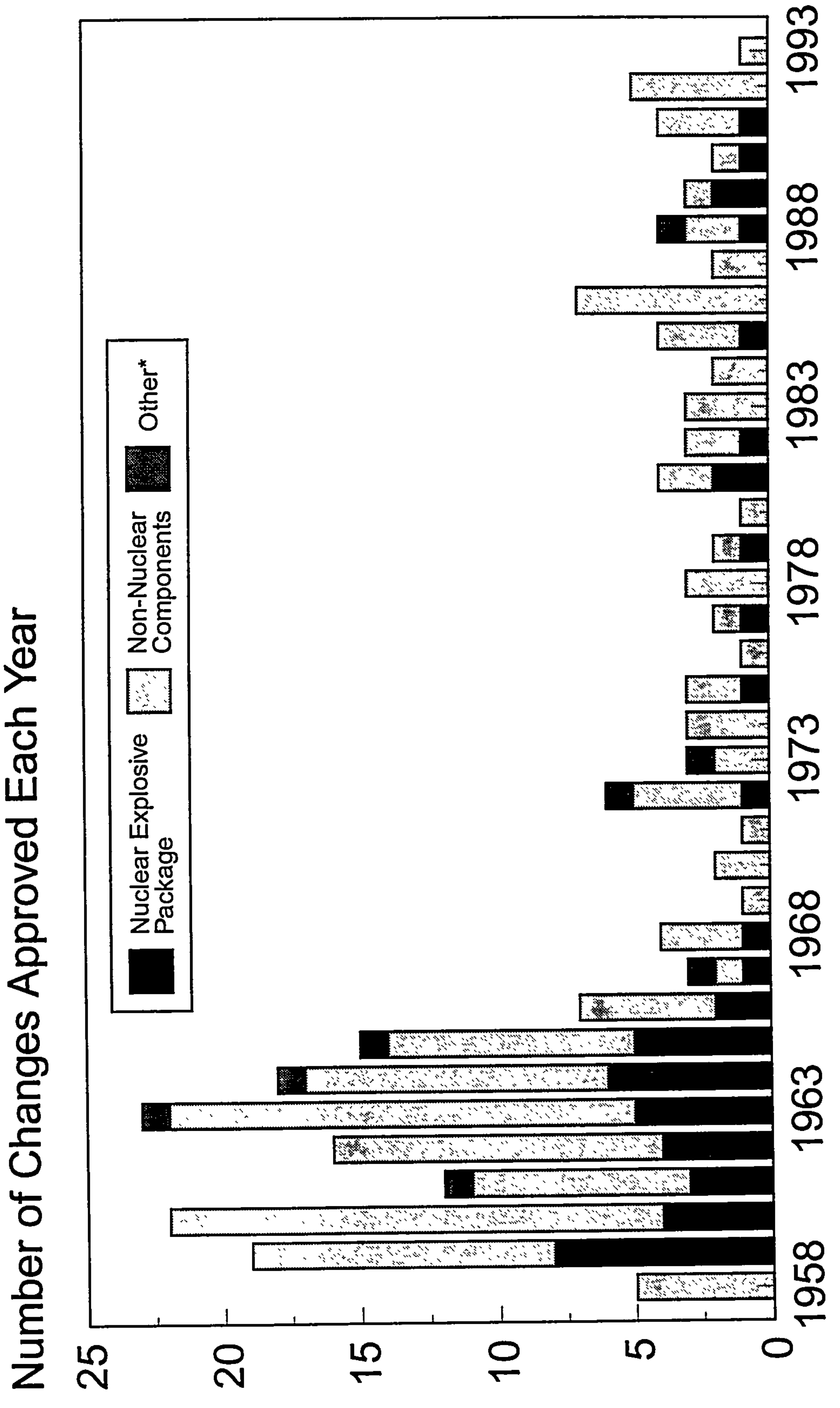


Figure 12. 210 "Major" changes since 1958.



* Other includes Handling, Training, Testing gear, weapon assembly and weapon identification markings

Figure 13. Findings for the planned stockpile.

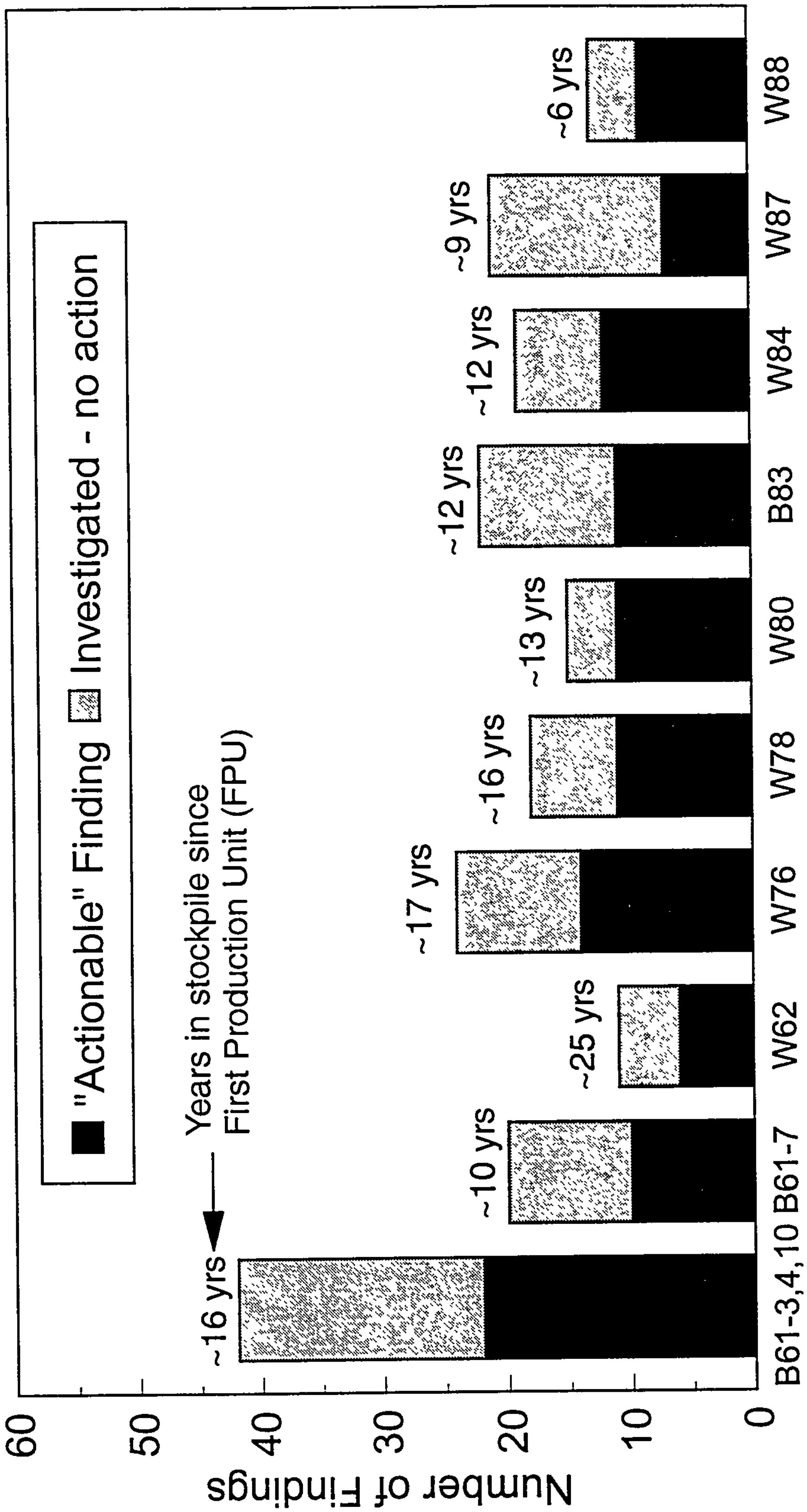
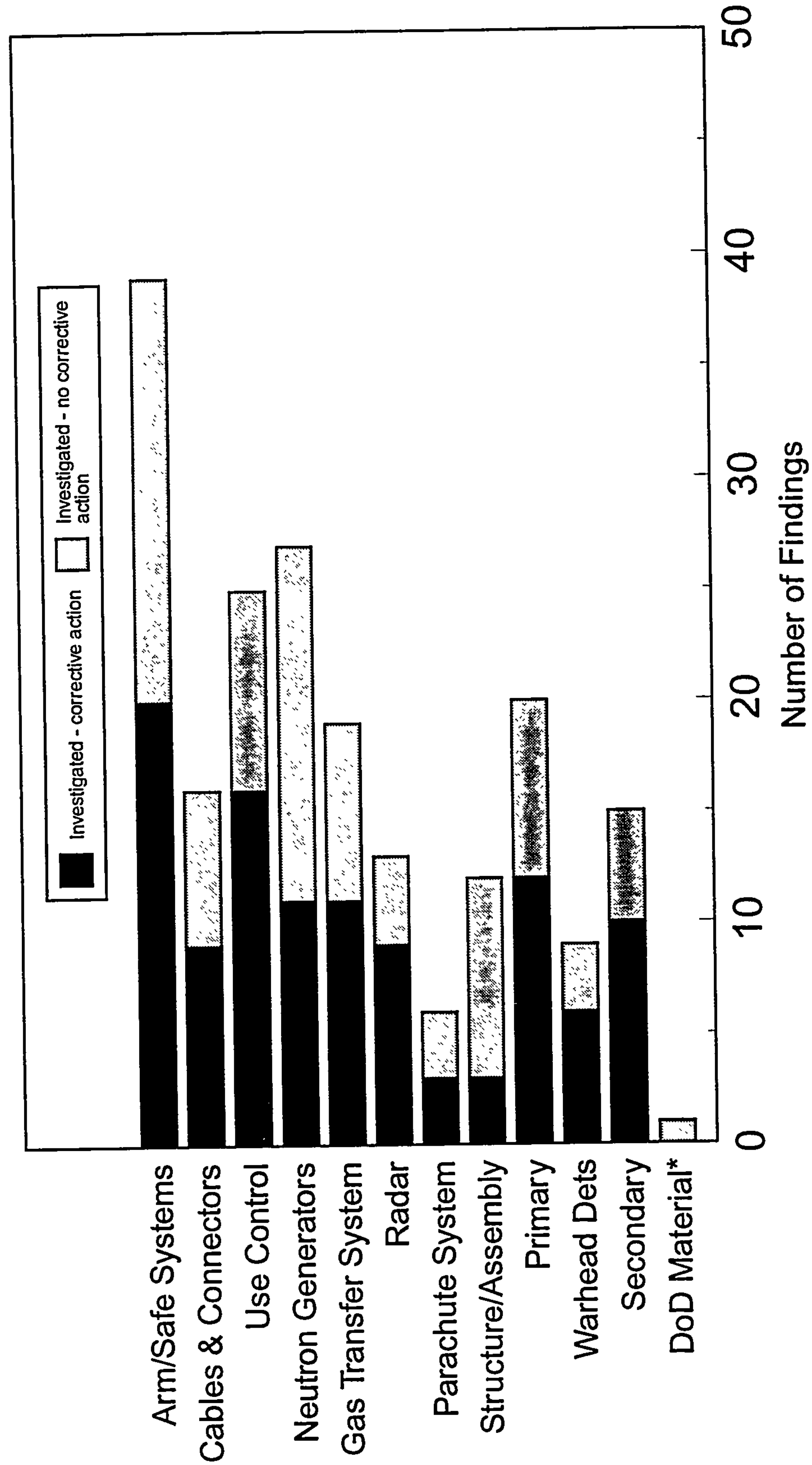


Figure 14. Findings by component type for the planned stockpile.



* DoD material refers to parachute problems prior to parachutes becoming Sandia responsibility, Army fuze findings and other DoD material findings uncovered in Stockpile Evaluation testing.

Figure 15. Year after First Production Unit when "actionable" findings are discovered for the planned stockpile.

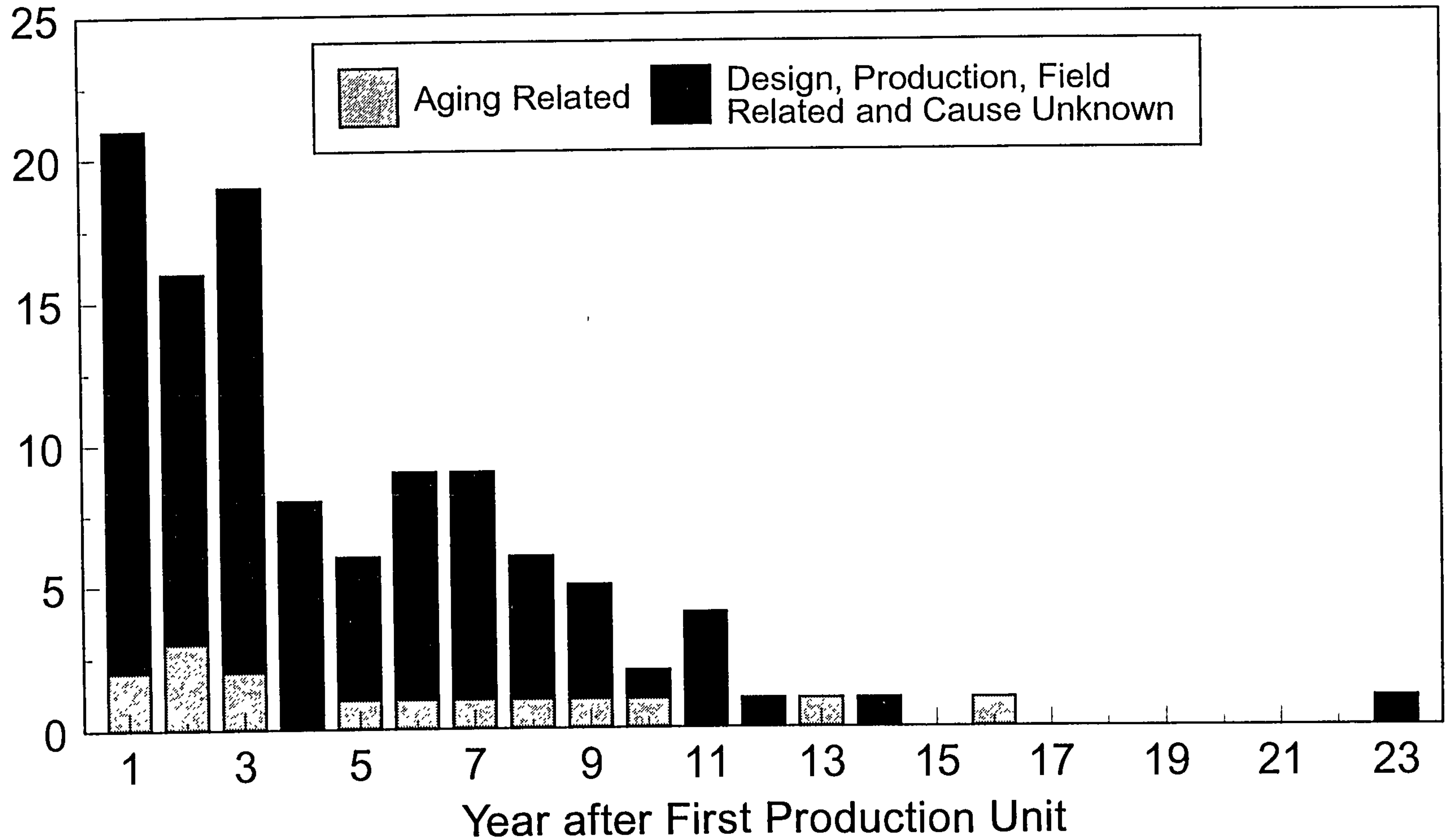


Figure 16. "Actionable" findings have resulted in retrofits and major design changes for the planned stockpile.

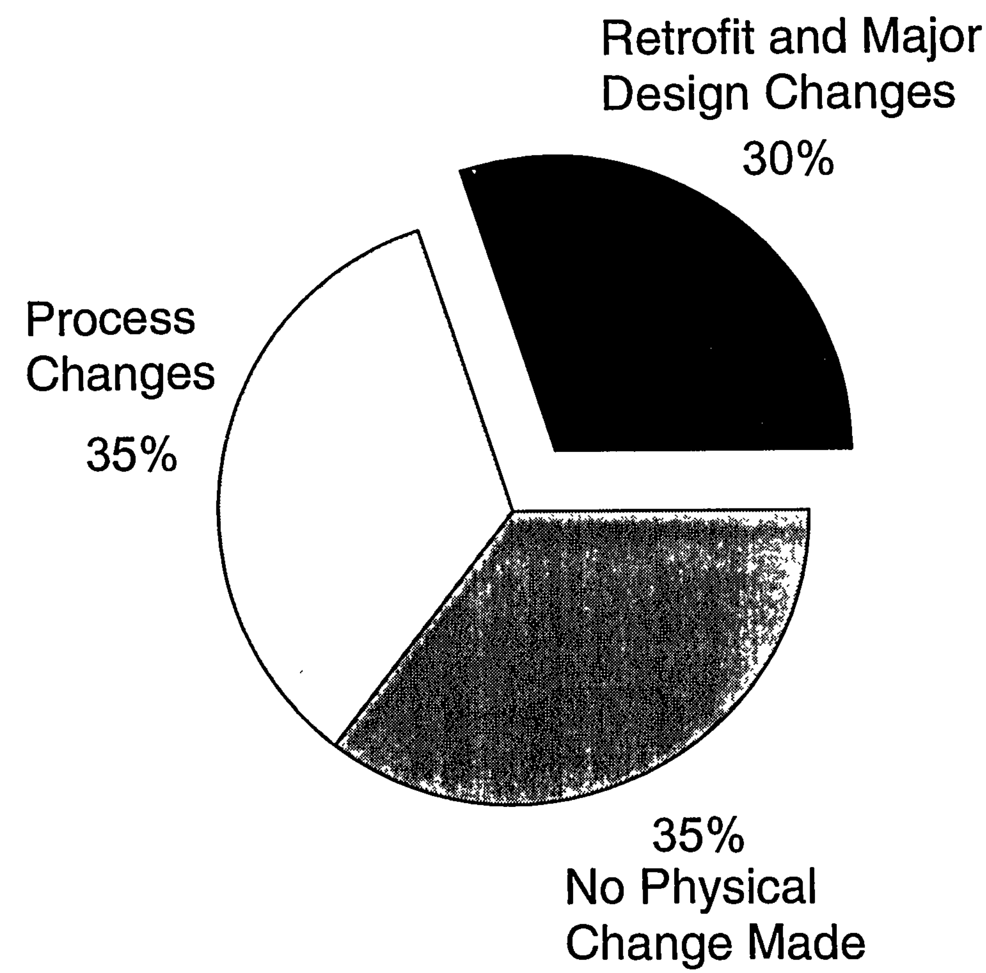
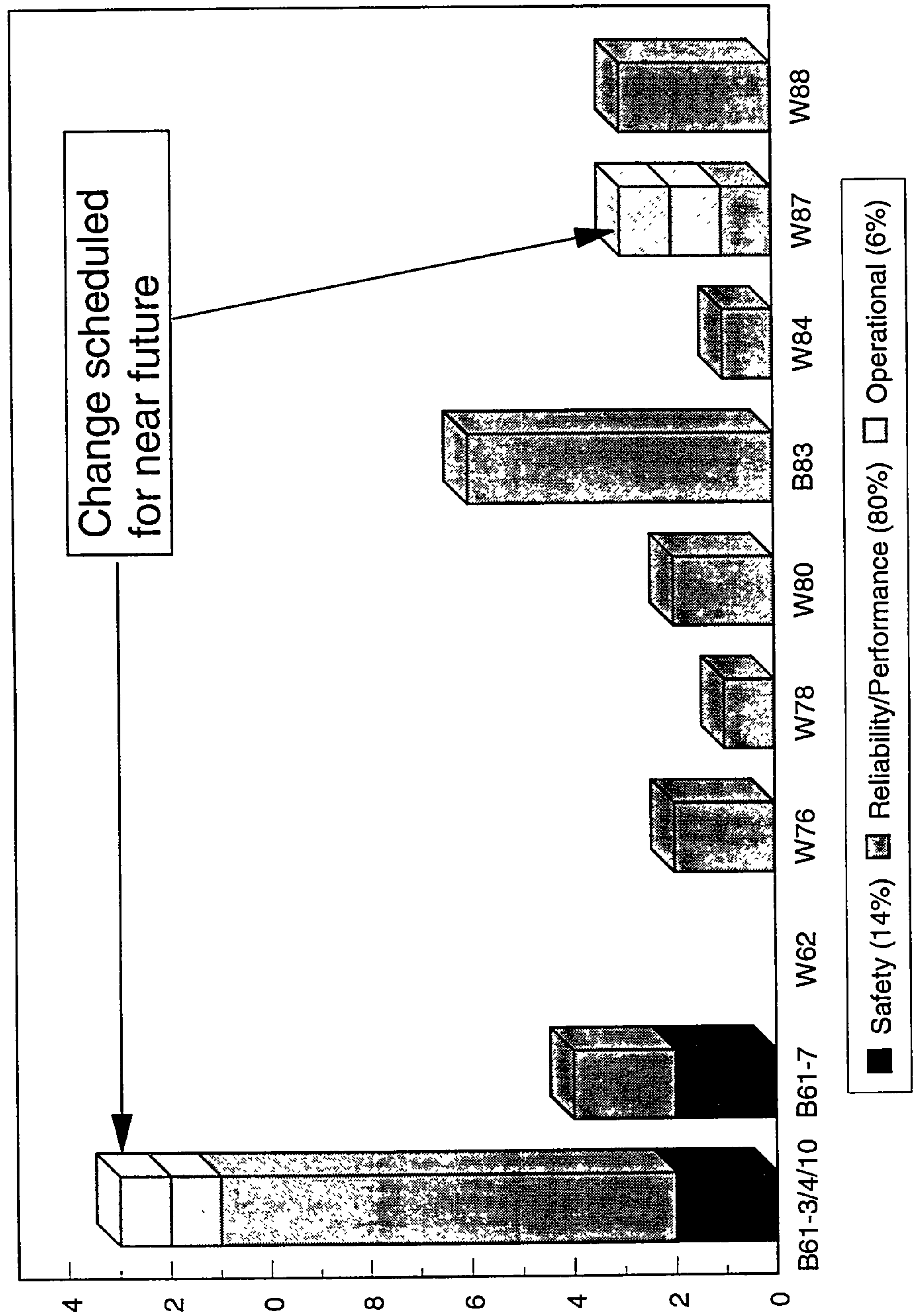


Figure 17. Changes to the planned stockpile.



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