Red 15

# A BRIEF HISTORY OF FIRE PROTECTION IN THE UNITED STATES ATOMIC ENERGY COMMISSION

1947 - 1975

by

Walter W. Maybee
Fire Protection Engineer
U.S. Department of Energy

Prepared for presentation at the
National Fire Protection Association
Fall Conference, 1978

# A BRIEF HISTORY OF FIRE PROTECTION IN THE UNITED STATES ATOMIC ENERGY COMMISSION

1947 - 1975

by

Walter W. Maybee
Fire Protection Engineer
U.S. Department of Energy

SUMMARY

In the 28 years in which it grew from a temporary war-time bomb development program to over thirty billion dollars worth of facilities housing much of the nations advanced research efforts, the Atomic Energy Commission set many records for safety. Among the best was a cumulative fire loss ratio of 1.2¢ per $100 of value.

A 1969 fire, one of four in its history that exceeded $1 million in loss, incurred $26 million damages and prompted major additions to the fire protection programs. The added programs, encompassing additional fire protection engineers, new protection systems, independent inspection programs and new performance-based goals resulted in an order-of-magnitude improvement. The cumulative fire loss ratio after 1969 was 0.06¢ per $100 of value, a record few industries have ever achieved.

## CONTENTS

# A BRIEF HISTORY OF FIRE PROTECTION IN THE UNITED STATES ATOMIC ENERGY COMMISSION 1947 - 1975

## INTRODUCTION

The United States Atomic Energy Commission was formed in 1947 as a new civilian agency of the federal government. The organization acquired the facilities and programs of the Corps of Engineers Manhattan Engineering District which had created the atomic bombs of World War II.

Building on the early weapons work, the AEC came to encompass major new programs; including operation of the nations multidiscipline national laboratories, major high energy physics research facilities, the development and regulation of peaceful uses of atomic energy (notably nuclear power reactors, which now produce more of this nation's power than did all generating sources in World War II) and extensive research in many physical and biological sciences. Im addition, the production capability for reactor and weapons materials was expanded far beyond the original levels. As an illustration, while the total investment in the World War II bomb effort was a then-astronomical two billion dollars, the estimated replacement value of all AEC-owned facilities at the end of 1975 was in excess of thirty billion dollars.

The Atomic Energy Commission ceased to exist in 1975 when the Nuclear Regulatory Commission was formed from the regulatory staff of the AEC, and the operating side was combined with some research centers operated by the Bureau of Mines to become the Energy Research and Development Administration or ERDA. Similarly, in 1977, ERDA was combined with some non-nuclear regulatory agencies, naval petroleum reserves and power marketing agencies (such as Bonneville Power Administration) to become the Department of Energy.

At its peak, the Atomic Energy Commission was staffed by about seven thousand federal employees. Essentially all programs and facilities of the AEC were government-owned, contractor-operated facilities with a peak employment of about one hundred and twenty thousand non-federal employees. While AEC programs involved research at the limits of scientific knowledge and hazardous materials and processes of all types, including many not previously existing, a safety record was established in all areas that was seldom exceeded by any industry and could well serve as a model for all. The performance in fire protection was especially noteworthy and bears recording.

In the 28 years of AEC existence, the total losses from all accidental causes, including fires, explosions, electrical, materials handling, radiation/decontamination incidents, materials losses, transportation incidents, acts of nature, and miscellaneous causes amounted to just under $68 million. Of this total, fires accounted for 60%, or just over $40 million. The cumulative loss ratio for the entire period was 2.0¢ per $100 of property values. For fire alone, the ratio was 1.2¢ per $100 of value.

During this period there were only six losses that exceeded $1 million. Four of these were fires and one, the 1969 Rocky Flats fire, resulted in a loss of $26,473,000 or nearly 40% of the total from all causes over the 28 years.

For any industry, this record would be outstanding. Considering the high values of some AEC facilities and the hazards and values of the "raw materials" of the nuclear industry, the record is even more noteworthy. For instance, the losses include accidental tritium releases which were included at a commercial value of 55¢ per curie. A gram of tritium contains 9,650 curies, so the loss of one gram results in a recorded loss of over $5,000. The high concentration of values is further illustrated by the Rocky Flats fire, which involved about one-fourth of one building, or by a gasseous diffusion plant fire in which the nearly $3 million loss would have exceeded $160 million if sprinklers had not been present.

As outstanding as the record is, the truly remarkable facet is that the cumulative fire loss record for the years 1947-1968, prior to Rocky Flats, was 0.65¢ per hundred dollars of value and, for the period after Rocky Flats (1970-1975) it was 0.06¢ per hundred dollars of value. An order-of-magnitude reduction in any endeavor is outstanding. When the reduction is from an already low base, it is doubly worth describing how it was achieved. This is that story.

# PRE-ROCKY FLATS HISTORY

## Problems and People

When the AEC was formed in 1947, it inherited the programs and facilities of the wartime Manhattan Engineering District which had been created solely as a crash program to develop an atomic bomb. While many buildings were both substantially built and provided with automatic protection, this was generally the exception, rather than the rule.

With the onset of the cold war in the late forties and the expansion of production facilities in the fifties, a new sense of urgency existed and other facilities were adapted to AEC needs. For example, the second weapons design laboratory, at Livermore utilized a World War II Naval air training field and a surplus aircraft engine manufacturing plant was converted to weapons component manufacturing, sharing half of an over 2 million square foot building with a GSA warehouse.

When civilian reactor development started at Idaho, it was assumed that most of the facilities would be temporary and the problems of adapting a former navy gunnery range were compounded by the installation of spiral-weld steel pipe water mains for the new reactor development areas. The last of the five-year estimated life pipe is now being replaced - after 20 years service!

At one facility a 1930's Civilian Conservation Corps wood frame building was used as office space into the 1970's when its "temporary" life finally ended. It was never sprinklered for the same reason it lacked good lighting and ventilation: the roof was too flimsy to support any.

Fortunately, the problems of inherited temporary facilities, massive new construction programs, and establishment of many new research laboratories and facilities was also accompanied by an expansion of safety activities. While nuclear safety had always been a dominating factor from the start, the number of industrial safety and fire protection people during the war was limited to a few Corps of Engineers people and some from the private firms that operated the bomb development program, such as DuPont and General Electric.

The AEC continued the program of university and private corporation operation of facilities, with AEC personnel functioning as program and contract managers under decentralized field office operations. Each field office had established a separate safety section by 1960 which included professional fire protection engineers. Most offices had fire protection engineers long before then, but they frequently operated within a general engineering branch, rather than as part of a coordinated staff of all safety disciplines.

The AEC was exempt from civil service and this enabled it to obtain a high-quality level of experienced personnel* by seeking the people it needed and to obtain them by being able to offer generally higher grades than other government agencies. Most of these people came to AEC with many years experience, primarily in the improved risk insurance industry or insurance rating bureaus.

The background and experience of the "first-generation" of AEC fire protection engineers led them naturally to adaptions of the "improved risk" or "highly protected risk" philosophy as the AEC standard and, indeed, the first AEC fire protection requirements specifically stated that the "improved risk" level of protection was the AEC goal.

Dissemination and coordination of fire protection activities was facilitated by annual meetings of all AEC fire protection engineers, annual general safety meetings, specialized committees (high explosives safety engineering, high energy accelerator safety) and the publication and wide dissemination of Health and Safety Information Bulletins and Serious Accident Bulletins.

While the fire protection deficiencies of inherited buildings had not all been cured by the time of the Rocky Flats fire, the control system had been established, new facilities were being well protected and most major contractor-operated facilities had added professional fire protection engineers to their own staffs. That this system was able to respond quickly, and prove its' worth was proved by the two Paducah fires.

*A 1965 study of safety staffing in the AEC showed a mean experience of 16 years for each of the 12 fire protection engineers; 10 years in prior service and 6 years with the AEC.

The Paducah Fires

The gasseous diffusion plant history offers some of the most dramatic examples of fire protection experience. The original plant (K-25) at Oak Ridge, Tennessee, was built during World War II as one of three experimental uranium separation processes and proved to be the most successful concept.

During the 1950's, the production capability was greatly expanded. The original K-25 facility was closed and three large new plants built at Oak Ridge, Tennessee; Paducah, Kentucky; and Portsmouth, Ohio. The 11 diffusion buildings at these sites were all built under crash programs to essentially the same design. The buildings are of high-bay, two story, non-combustible construction with insulated metal deck roofs and total over 20 million square feet in area, the largest three being nearly 3 million square feet under one roof.

At all three plants, onsite fire departments supplemented the extensive protection systems. Sprinkler protection was provided for offices, laboratories, shops, transformers, and cooling towers. The diffusion buildings themselves were not sprinklered due to the lack of proven fire hazards, limited combustible contents, and supposedly noncombustible construction. Gravity-feed lubricating oil systems were a recognized hazard and extensive hose systems and even inbuilding 500 gpm pumper trucks were provided to combat potential fires.

Following the General Motors transmission plant fire at Livonia, Michigan, in 1953, the hazard of certain types of metal deck roof and roof covering combinations became apparent and it was recognized that the diffusion plants had roofs of the type capable of undergoing a self-sustaining combustion originating from what would otherwise be a localized fire.

Before evaluations of the diffusion plant roof problem could be completed, a 70,000 square foot building at Paducah plant suffered the complete loss of the roof from a fire on November 11, 1956, when a compressor gas seal leak resulted in an intense localized oil fire that ignited the underside of the roof deck. One firefighter was seriously injured in a fall during efforts to escape from the intense heat and, although little damage was suffered by the process equipment, the total loss due to collapse of the roof was $2,100,000, the fourth largest loss in AEC's history.

Following the fire, the hazards evaluation project was intensified. As well as the AEC evaluations, the process building hazards were surveyed by management-level, security cleared personnel of both the Factory Insurance Association and the Factory

Mutual System and evaluation of sprinkler criteria for the oil hazard was done by Factory Mutual Laboratories. Full automatic sprinkler protection was chosen as the best of several alternatives and the plants were completely sprinklered between November of 1957 and June of 1961 at a cost of $17,626,000 (an underrun, incidentally, of nearly $900,000 from the authorized cost).

Because of the vast size and value of the diffusion buildings, and the impracticality of firewall subdivisions, the reliability of the systems was of utmost importance. Design criteria was based on a maximum of 400 heads per sprinkler system (at a 120 square foot per head maximum spacing) and water supplies calculated on the basis that, with a system out of service, four peripheral systems could discharge 1,5000 gpm each with a reserve of 1,500 gpm. Waterflow and valve supervision was provided for all systems.

In addition to being completed at a cost considerably under the authorized funding, the sprinkler installation project established the all-time National Safety Council record of over three million injury-free man-hours in the public utility construction category by the Grinnell Corporation as principal mechanical subcontractor. This despite the difficulties of installations in high-heat areas and roof heights of 85 feet.

Dramatic proof of the system's capability came on December 13, 1962. A small lube-oil fire earlier that month had been successfully controlled by three sprinkler heads, but on this date, an explosion, followed by an intense local chemical-reaction type fire caused heavy damage to a cell at the Paducah plant. Water from overhead sprinklers was rapidly converted to steam which opened most of the 2,341 sprinkler heads that operated during the fire. This is believed to be the all-time record for number of sprinkler heads successfully operating in a fire. Peak flow was 40,000 gpm for a working density of 0.146 gpm/sq.ft. The 66-8" sprinkler risers in the building were fed from a dedicated 14" and 16" loop about the building supplied by a 300,000 gallon gravity tank, elevated 275' above grade and four fire pumps of 4,625 gpm capacity at 125 psi each, taking suction from a 2,600,000 gallon reservoir. Heads on 23 systems operated, consuming some 2,800,000 gallons of water. The sprinklers extinguished the fire and only one manual hose line was necessary to complete extinguishment of an expansion joint seal on the roof.

The loss totalled $2,900,000 (most of the damage being due to the original explosion), for the third largest loss in AEC history. Despite the magnitude of the loss, it was evident from the 1956 lesson, that the loss in this building would have been on the order of $160,000,000 if the sprinklers had not prevented the roof fire from propagating. Thus, this major protection project not only paid for itself in a dramatic demonstration, but probably saved enough to pay for the cost of every sprinkler installed in AEC history.

ROCKY FLATS FIRE

The story of the May 11, 1969, fire at the Rocky Flats plutonium facility has been described in detail in the January 1970 Fire Journal article by D. E. Patterson. The fire originated from spontaneous ignition of plutonium briquettes in a storage box in a glove box line and spread to involve combustible shielding material in the box and the conveyer lines.

Because of the impact on AEC operations and fire protection programs, the fire marks a dividing line in the history of AEC fire protection.

Two misconceptions regarding the fire remain in the realm of public mythology and deserve further comment. The first is a belief that the fire led to the conclusion that water (sprinklers) can safely be used in facilities handling fissionable materials. It is true that, since water is a neutron moderator, a non-critical assembly of fissionable materials can be made critical with some configuration of water. As an example of the extremes of nuclear safety consideration, there did exist cases where water was banned, even though the facility was designed to be safe under totally flooded conditions!

Water prohibition became an example of the response to the "what-if?" conditions of nuclear safety critics. If there was no water, you didn't have to worry about accidental material configurations and water causing a problem. This attitude had been objected to on the basis that fissionable materials could be used in conjunction with combustible materials, in sufficient quantities, where water was the only feasible extinguishing agent. A criticality accident tends to be self-limiting; after an initial burst of neutrons the assembly disassembles to a non-critical mass. A 1946 critical assembly accident involving eight people in one room killed one person. The same weight of high explosives detonating, or gasoline flashing, would have killed everyone in the room. Fire on the other hand is also a chain-reaction that can, and does, kill hundreds in a single incident.

Regardless of the criticality-water arguments, the debate was resolved long before Rocky Flats. The best illustration being Rocky Flats itself, where a new plutonium building was just beginning operations at the time of the fire. It was fully sprinklered.

The second myth remaining about the Rocky Flats Fire is the cost. Congress authorized $45 million in funds for the restoration project and this figure was still used by AEC when the publication WASH 1192* was issued. The restoration project, covering eight phases, was completed and final costs reported on May 7, 1975. The total cost, including decontamination and plutonium recovery was less than $41 million. Over $13 million of this was spent in upgrading facilities not involved in the fire. The actual cost of restoring the building was $26,473,000 of which $9,999,000 was the cost of decontamination, and $517,000 was the cost of reprocessing plutonium.

Plutonium is one of the few materials in which the "ashes" can be converted back into the product that burned. In fact, a plutonium transportation fire is a misnomer since plutonium is usually "burned up" (converted to plutonium oxide) before shipping.

The upgrading projects at Rocky Flats, besides completing sprinkler installations, included changing to inert atmosphere operations in critical glove box lines (a$5 million project in itself) and added protection systems, including deluge water spray, for filters.

## POST-ROCKY FLATS PROGRAMS

Three steps of major importance were taken following the Rocky Flats fire. As described in the AEC General Manager's Letter of December 16, 1969, to the Chairman of the Congressional Joint Committee on Atomic Energy, these were:

a. Evaluations of the condition of AEC-owned facilities including the identification of any deficiencies that may exist and recommendations of corrective actions that are deemed necessary to assure safe and reliable operations.

b. Reviews of the adequacy of the organizational arrangements of operating contractors for assuring fire safety both in facility design and in operating practices.

c. Separate from but related to the studies by the field offices and operating contractors are the detailed fire protection surveys of key AEC facilities for which AEC has contracted with the Factory Insurance Association and the Factory Mutual Research Corporation.

*WASH 1192 Operational Accidents and Radiation Exposure Experience Within the United States Atomic Energy Commission 1943-1975. Available from NTIS, Springfield, Va. 22161, $6.95 printed, $4.25 microfiche Fall 1975

These commitments resulted in the following programs:

Physical Upgrading Program

A list of all projects deemed necessary to upgrade all AEC facilities was completed by early 1970 and resulted in a package of planned improvements exceeding $265 million. Most of this was intended for new facilities and improvements categorized as "adequacy of operating conditions". In fact, over half of the total was for two new plutonium research, handling and waste treatment buildings. Major pollution control projects were also included.

Congress appropriated an initial $26 million in supplemental funding and this was used to complete the eight most important projects and institute design of the plutonium facilities. Additional funding was obtained in subsequent years on a project-by-project basis.

Fire protection projects in this program were later combined with recommended improvements resulting from the insurance survey program and most of these projects are now complete.

Organizational Changes

Studies of safety organizations within AEC were completed in 1970. While there were almost as many organizational arrangements as there were facilities, the opportunity for several improvements in the fire protection and other programs existed and the Joint Committee on Atomic Energy was advised of the following actions on February 1, 1971:

1. Each contractor operating a vital AEC facility shall include in the safety organization at least one professional fire protection engineer.

2. Where appropriate, fire protection specialists shall be provided within contractor organizations to deal with unusual or unique problems. It is intended that these specialists will be made available to other AEC contractors as required.

3. A system shall be established requiring a safety analysis of all operations on a continuing basis and a safety analysis prior to the construction of all new facilities or modifications of existing facilities.

4. A system of internal management audit of the fire safety program shall be provided at each major contractor facility.

5. Field office audits and in-depth inspections in the fire safety area should be strengthened.

Most of these programs already existed to some extent in most major sites but this action broadened the programs and made them applicable to all major facilities and projects.

Insurance Survey Program

The third program element of the post-Rocky Flats evaluations consisted of independent appraisals of the weapons manufacturing system.

Both the Factory Insurance Association and Factory Mutual Research, representing the major "improved-risk" insurance interests were asked to conduct the surveys. Both agreed and devoted their top engineering talent to the program.

Between September of 1969 and December of 1970, about 20 engineers from each company devoted a total of over 9,000 man-hours to the surveys.

The 18 reports resulting from these surveys contained 750 recommendations. While the number may seem high, it should be viewed from the aspect that it represented one recommendation for each day and-a-half of work.

The General Manager of the AEC also directed a survey of all instances where facilities were not in conformance with AEC protection criteria. Facilities would either be brought into compliance or require a formal exemption approved by the General Manager. This was expanded to include the insurance survey team recommendations. As a result, of the 750 recommendations, only eight exemption requests were allowed. In total about 40 exemptions were granted in the next five years. Almost half of these have since been eliminated by compliance actions.

Following appraisals of up-grading actions, AEC management decided to extend the survey program to all major facilities. Contracts were extended with both FIA and FMEA and, by 1974, all facilities with a replacement value in excess of $25 million had been surveyed.

The complete first round of surveys, including the weapons facilities, resulted in 58 reports containing some 3,989 recommendations encompassing 33,455 man-hours of work. Again, this was less than one recommendation for each man-day. More significantly perhaps, it translates to one recommendation for each $7 million in property values.

The program continues with each site being surveyed at 3 to 4 year frequencies. By the time the AEC was formed into ERDA in 1975, all weapons facilities had been surveyed twice. Resurveys took about half the time of the original surveys and confirmed that about 99% of the original recommendations had been satisfactorily resolved. (Ironically, the first facility to achieve 100% compliance was subsequently closed).

## Fire Protection Standards

In addition to the three programs above, the directive covering the fire protection requirements of the AEC was changed to more clearly spell out the performance nature of the system. This had always been implied by the requirements for, and definitions of "improved risk" but the new revision left no doubt as to the goals of the system. They were spelled out as follows:

0552-02 OBJECTIVES

021 To obtain and maintain a level of fire protection adequate to assure that fires and related perils will not result in hazardous exposure of the public and employees, unacceptable impairment of DOE programs, or excessive damage to or loss of government property.

022 To establish an "improved risk" level of fire protection sufficient to assure that:

a. there is no undue hazard to life from fire.

b. significant offsite contamination or pollution shall not occur as the result of fire.

c. automatic extinguishing systems are provided to limit the maximum credible loss from a single fire to less than $1,000,000.

d. areas and/or values subject to fire damage are limited to the extent that the maximum possible fire loss, assuming failure of the automatic systems, shall be limited to $25,000,000.

e. vital AEC programs will not be curtailed as the result of fire or fire related incidents.

The definition of "improved risk" was defined as follows:

041 Improved Risk. This term has the same meaning and

intent as is commonly understood when this term is used in the insurance industry. The term involves the use and application of judgmental factors and thus does not lend itself to a precise fixed definition applicable in all locations and all situations. In general, "improved risk" protection necessitates full compliance with the fire protection and loss prevention standards detailed in Appendix 0550, "Operational Safety Standards." This term also implies that professional fire protection engineering judgment (with full benefit of past fire experience) has been used to obtain the highest economically justifiable level of industrial loss prevention. Generally, an improved risk property is one that would qualify for complete insurance coverage by the Factory Mutual System, the Industrial Risk Insurers, and other industrial insurance companies that limit their insurance underwriting to the best protected class of industrial risk. Essential elements of a program complying with the improved risk concept are included in appendix 0552, part I. The most evident characteristic of an improved risk property is the existence of reliable, automatic fire extinguishing systems throughout all buildings of combustible construction or contents.

The "maximum credible" and "maximum possible" fire losses were defined as follows:

047 Maximum Credible Loss. The maximum loss that could occur from a reasonable combination of events resulting from a single fire. Considerable judgment is required to evaluate the full range of loss potentials, but in general, readily conceivable fires in sensitive areas are considered. Examples are power wiring failures in cable trays, flammable liquid spills, and high value parts storage areas or combustible exposures to sensitive machines. Any installed protection systems are assumed to function as designed. Due to the uncertainties of predicting human action, the effect of fire brigade response is generally omitted except for post fire actions such as salvage work, shutting down water systems, and restoring production.

048 Maximum Possible Fire Loss. The maximum foreseeable loss which could occur in a single fire area in the assumed absence of both automatic and manual fire extinguishing actions. In determining loss, the estimated damage to the building and its contents shall include replacement cost, less salvage value, plus the cost of decontamination and cleanup. Effects upon program continuity, auxiliary costs of fire extinguishment, and consequent effects on related areas should

be included if the effects can be cost determined.

A section on acceptable means of compliance with the stated goals included these items regarding attainment of the dollar loss limitations:

C. $1,000,000 LOSS POTENTIAL

The objective of limiting fire loss potential to $1,000,000 may be considered to have been attained when:

1. an automatic fire extinguishing system is installed in any facility where a single credible fire could cause a loss in excess of $1,000,000 in the event that such a system is not installed and manual firefighting efforts are assumed to be ineffective.

2. the values, nature of the contents, or subdivision by firewalls is such that a $1,000,000 loss from a single fire is not credible.

D. $25,000,000 LOSS POTENTIAL

The objective of limiting the maximum single fire loss to $25,000,000 assuming a single failure of the installed protection system and ineffective manual firefighting, can be considered to have been obtained when:

1. the values, nature of the contents, or subdivision by firewalls is such that it would not be credible for an uncontrolled fire to result in a loss of this magnitude.

2. redundancy of protective systems is provided to the extent that, even with a single failure of a system, the resultant loss will not exceed $25,000,000.

Further sections of the fire protection criteria covered responsibilities and authorities of various headquarters and field organizations, reporting requirements, exemption procedures, the insurance company survey program, and an expanded section on essential elements of an improved risk facility. One section noted that extinguishing systems may be required even though dollar loss potential is acceptable, or even nil, if warranted by exposure, favorable cost/benefit ratios, public acceptance, or probable future changes in occupancy or value.

Other Programs

Several other programs developed by the AEC had a favorable impact on fire protection. AEC Public Safety Liason Officer, Frank Brannigan, developed a series of courses on Fire Loss Management that concentrated on informing non-fire protection professionals of fire protection concerns in building construction, design, and facilities management. These courses were conducted for AEC and contractor personnel twice yearly and the program continued under contract after his retirement. In addition to materials developed specifically for the course, his book on Building Construction For The Fire Service was used as a basic text. In conjunction, Pat Phillips of the AEC's Nevada Operations Office (and Chairman of the NFPA Signalling Systems Correlating Committee) covered new developments in fire protection, while noted guests such as Tony O'Neill of NFPA, and Hank Collins of Underwriters' Laboratories explained the functions of their organizations. This program was noteworthy for spreading the fire protection message across AEC operations; over 300 people from AEC facilities attended in the last 5 years of AEC history.

Lessons from losses were always of major importance and a major step forward was achieved with Bill Johnson's development of the MORT (Management Oversight and Risk Tree) program. Similar to fault-tree analyses, this provided a powerful new tool for examining the root causes of accidents. The technique became required for all AEC accident investigations and was widely taught throughout the system. MORT workbooks were published for public distribution and the technique is finding wide acceptance outside AEC.

In conjunction with MORT, a series of two week accident investigation courses was begun and a trained corps of accident investigators developed. Those trained also receive a formal refresher training course at subsequent intervals.

Finally, a Systems Safety Center was developed by Dr. R. Nertney at what was then called the National Reactor Test Site in Idaho. Since AEC, this operation has become of major importance and has developed many publically-available documents on risk management, human factors in design, preparation for accident investigation, and other safety subjects.

All of the above programs contributed to the ultimate achievement of the AEC fire protection system; an order-of-magnitude reduction in fire losses. In the face of potential losses of high order and on top of a program that had already held actual losses to a low level, the loss ratio for the final five years of AEC was reduced to 0.06¢ per hundred dollars of value. In the entire 28-year history of the AEC, the loss from fire was only 1.2¢ for each hundred dollars of value, truly the story of an "improved risk" industry.

None of the above has directly addressed personnel safety. That is because, from the fire protection standpoint, it never became a problem. In the combined 32-year history of MED-AEC there were 321 fatalities. Of these, radiation killed 6 people - and none since January 1961. Burns (of all categories) killed 17 people - and none since January 1966. Over half of all fatalities, from all causes, occurred in construction projects, not in operating plants. The AEC fatality and injury rates, including construction, were consistently one-third, or lower, of the National Safety Council's all-industry rate. And, finally, no fire death has ever occurred in a sprinklered building.

## GENERAL FIRE PROTECTION PROGRAMS

### Fire Research

Fire research was never a function of the AEC but a considerable number of projects were conducted in-house that were related to specific AEC fire problems. Most notable of these is the extensive filter program at Lawrence Livermore Laboratory (LLL).

LLL was also a leader in early smoke tests, using the Bureau of Standards smoke chamber, and much of the work conducted by Jim Gaskill at LLL is applicable today.

Other laboratories have done in-house testing and published reports relating to their work. Most notable are the Union Carbide programs at Oak Ridge on computer design of sprinkler heads, carbon microspheres as an extinguishing agent, high rack storage, and cooling tower protection systems.

Union Carbide's Oak Ridge facilities were also instrumental in developing a protection system for cable trays consisting of bagged vermiculite placed on the trays. In use at several AEC facilities, it proved to be cheap and effective and presented no obstacles to rearranging or installing new cables.

Probably the earliest work was done at the New York Operations Office in 1949, relating to the use of dry chemicals on ether fires.

A number of other in-house research projects included sodium fires, a fire fighters suit for sodium and protection of large hot cells at Richland. Savannah River studied protection of large cells and canyons. Idaho investigated the use of high-expansion foam in records-storage facilities and LLL developed a high-expansion foam system for glove boxes.

Work on friction loss in small hose by Chief Purington at LLL led to revisions in long-standard friction loss formulas and are incorporated in his text on fire service hydraulics.

A quick indication of the extent of these projects is given by the fact that the first 40 issues of Fire Technology contained 13 articles generated by in-house AEC research and the 14th edition of the NFPA Handbook contains AEC-generated references in the bibliographies of 23 separate chapters.

Some development work has resulted from in-house programs. Most notably, sodium fire extinguisher experiments at the Atomics International facility at Santa Susana, Ca. led to contract development of Na-X by Ansul Chemical, a new, los-chloride extinguishing agent.

A number of outside projects were conducted for AEC, such as the gaseous diffusion plant protection systems work performed by Factory Mutual Research following the first Paducah fire.

Computers

Computers have always been essential to AEC operations and their use has expanded greatly with time. By 1975 AEC had 3,485 computers and central processing units valued at nearly half a billion dollars. Of these, 324 were valued at over $200,000 each. The multi-discipline Lawrence Livermore Laboratory has acquired 31 computers since 1953 costing from $1 million to $9 million each.

At present there are 9 of these on site and at least 240 smaller units. The need is illustrated by an example from the laser fusion program. The solution of a typical laser fusion experiment, which may involve lasers impacting a nearly microscopic tritium-in-glass sphere involves solution of 100,000 coupled differential equations, each requiring 1,000,000 arithmetic operations - or a few hours on a CDC 7600 computer!

AEC supported the NFPA computer committee from the start and, at times, as many as four AEC or contractor personnel have served on the committee in various capacities.

NFPA standards have always been the referenced AEC standard, but the computer protection area is one in which an additional standard was developed for in-house AEC use*. This follows the recommendations of the former Federal Fire Council in requiring automatic fire extinguishing systems in these facilities (basically sprinklers although Halon 1301 is permitted).

AEC requires automatic protection for computer facilities with a value in excess of $1 million and limits maximum value in a single facility to $25 million.

Underfloor protection is provided in most facilities with halon predominating, although there are some $CO_2$, and even some sprinklers underfloor.

AEC experienced a number of fires inside computer equipment and some units have in-cabinet halon or $CO_2$ protection. However, there were no instances of underfloor fires or significant fires in either a computer room or tape storage/records vault.

## Cooling Towers

Cooling towers serve throughout AEC facilities in all the capacities found in private industry. In addition, very large towers are used in conjunction with magnet cooling systems at large accelerator facilities and the final stage of the motor-compressor cooling systems at the gaseous diffusion plants. A number of the diffusion plant towers exceed 20 cells per tower and cost over $1 million each.

The cooling towers at the diffusion plants were provided with dry-pipe sprinkler system protection, in accordance with the major insurance industry thinking of the time, in the 1950's (The NFPA cooling tower standard was not adopted until 1959). These systems served well under several fire incidents, including a 1966 fire in a $1.1 million tower in which the sprinklers held the loss to $500. However, the age of the systems, corrosion and maintenance problems, and the potential for a fire to out-race the closed heads resulted in a need for major revisions. This work was done in 1975 in conjunction with a cooling tower upgrading program that, in itself, was part of an ongoing uprating program for all three diffusion plants. An idea of the size and number of towers involved is illustrated by the fact that the sprinkler system upgrading alone cost over $3 million.

*WASH 1245-1 Standard for Fire Protection of AEC Electronic Computer/Data Processing Systems by Arnold A. Weintraub and Thomas P. O'Connor, July 1973.

The new systems, all deluge-type, have already extinguished two fires, one in late 1975 when an electrical short in a fan motor junction box sent hot metal fragments of the box cover onto the deck, igniting the top surface between two fans, and another in early 1976 when welding sparks ignited the deck between the fans. Damage amounted to several thousand dollars in each case as the deluge systems could not activate until the deck burned through to the underside, but in each case, a potential million dollar loss was averted as well as vital months of production downtime.

Paradoxically, the two largest cooling tower fires in AEC history resulted in no loss to the Government. In one incident, a tower for which protection had been recommended for some years was finally being replaced by a new tower when it burned. The old tower had been given to the construction contractor for salvage and the new tower was in service, so the loss occasioned no inconvenience to AEC. The other incident occurred at a major accelerator facility under construction in 1964. The tower burned from a welding spark, losing two of the three cells, but it was still the construction contractors' property so no Government dollar loss was incurred and it was rebuilt before the accelerator became operational, so the research program was unaffected. The tower was to be protected by a deluge sprinkler system which was not complete and, therefore, not a factor in the fire. Ironically, after the fire, it was discovered that the deluge piping was complete except for installation of one very short pipe flange. If the main control valve had been opened, the sprinklers probably would have received enough water to control the fire.

## Extinguishing Systems

The AEC always played a lead role in development and utilization of new extinguishing systems. When high-expansion foam was first introduced in the early 1960's, we acquired one of the first vehicle units and our fire departments acquired a number of portable generators. By 1965, fixed systems had been installed in a reactor and an accelerator and our latest system has been installed in a laser-fusion target building.

The development of Halon 1301 showed great potential for AEC applications and hundreds of systems have been installed in trailers, computer underfloor areas, control rooms, electronic equipment and special research areas. On the last year of AEC, 1975, fifty-five systems were installed. What is probably the world's largest system is currently installed in a half-million cubic foot fusion research machine room, supplementing an existing, manual 31-ton $CO_2$ system.

Halon systems are provided as portable plug-in systems for trailers at a number of accelerator facilities where university-owned trailers are moved into target buildings on a temporary basis where they may expose other sensitive equipment.

Dry chemicals and powders have a long history of application due to extensive use of flammable liquids and combustible metals in a wide variety of programs such as weapons and reactor research, which involve extensive use of exotic and combustible metals. The AEC also financed the development of several extinguishing agents such as Ansul's NAX for sodium fires. Oak Ridge has developed a carbon microsphere agent also suitable for metal fires. Probably the only fixed pipe Met-L-X system is installed for sodium fire protection at a breeder reactor site.

Automatic sprinklers have always been considered the first line of defense. Where other systems were installed, they generally are to supplement sprinklers. In addition to the benefits proven by the two Paducah fires, a study of 241 fires between 1970 and 1975 revealed the following:

The average loss in those fires where sprinklers operated was $2,882. The average loss in fires where sprinklers were not a factor was $7,074 or 2½ times the average sprinkler loss. In fact, if the 91 fires extinguished by portable extinguishers, at an average loss of $1,416 each, are eliminated, the average loss in the unsprinklered fires becomes $10,974 or nearly four times the sprinklered rate.

Fear of water damage has always been a major bone of contention between fire protection personnel and those who can readily visualize sprinklers operating accidentally. While the AEC had largely resolved these concerns, even before the Rocky Flats fire, an analysis of 1970-1975 experience offers further confirmation. In 16 incidents of sprinkler failures (mostly due to freezing or mechanical damage) the average loss was $1,485. In six other incidents of fire main ruptures, hose leaks, etc., the average loss was $1,836. In the same period there were 26 incidents of water damage from failures of non-fire protection water systems, and the average loss in these incidents was $6,552. Thus, the average water damage from a non-fire protection system was over four times the loss from a fire protection system failure!

Fire Departments

All AEC facilities were required to have strong emergency forces as part of their overall safety programs. Twenty major sites have full-time, paid fire departments. Two of these, at Los Alamos and Idaho are, government-employee organizations; the others contractor-operated. Most of these organizations also provide other emergency response capability such as ambulance and EMT aid and disaster response.

Mutual aid agreements are strongly endorsed for all facilities. However, a number of sites have no other departments within many miles and at Los Alamos, for example, the government fire department is also the only protection for the city of Los Alamos and two adjoining communities. Except for forest and brush fires, mutual aid responses to AEC facilities have been negligible. In fact off-site responses outnumber on-site mutual aid by a factor of 20 or 30 to 1.

Despite the fact that we support these forces at an increasingly strong level (recurring fire protection costs climbed from $7½ million per year in 1965 to nearly $15 million per year in 1975 - mostly due to inflation), it is not practicable to provide fire departments in sufficient strength to handle any emergency. This is another reason why primary reliance is placed on automatic protection systems with the fire department serving as another example of the backup or defense-in-depth philosophy.

AEC fire departments have always been among the leaders in innovative technology. The first Snorkel truck in California was acquired by the Lawrence Livermore Laboratory and the first high-expansion foam truck was acquired by the National Reactor Test Site at Idaho, after it had made a national demonstration tour. Argonne National Laboratory was the first to experiment with, and use, truck-mounted, light high-expansion foam units for laying fire breaks and fighting brush fires. We currently operate every type of fire department apparatus from aircraft crash trucks* to mobile command-post trailers.

*We run a commercial, 16 flight per day, airline service between Albuquerque and Los Alamos, via Ross Airlines.

Professionalism

The success of a fire protection program may be credited to the protective systems and structural features designed into a facility, but in the final analysis, credit must be given to those who are responsible for the existence of the systems and the existence of reliable back-up protection when a system fails. Much of the AEC's success can be attributed to acquiring and maintaining a professional and dedicated staff. Examples of the importance attached to this facet by the AEC and its contractors include the following:

Of the 94 fire protection engineers in the federal government in 1975, 20 were AEC employees.

Of the 1641 SFPE members in 1976, 14 were AEC employees and 18 were AEC contractor employees. This is 2% of the total membership, but the AEC people were 23% of the federal government-identified members, and the contractors were nearly 10% of the non-fire equipment manufacturing industry members.

Nearly 2% of the 1976 membership of the NFPA's Industrial Fire Protection Section came from the AEC and its contractors - 43 people in all.

In 1974, the AEC and its contractors had 21 positions on 15 different NFPA committees or sectional committees, including a committee secretary and two chairmen. In the period 1965-1975, there were 14 articles in Fire Journal and 13 in Fire Technology that were originated by AEC. And, finally, in the 14th edition of the NFPA Fire Protection Handbook, the bibliographies of 23 separate chapters contain one or more references that are the result of work performed by the AEC or its contractor people.

********