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Automatic Sprinkler System Performance and Reliability In United States Department of Energy Facilities

1952-1980

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U.S. Department of Energy
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Environmental Protection, Safety, and
Emergency Preparedness

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In
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Part B Non-Fire Experience

Summary

This report analyzes the automatic sprinkler system experiences of the United States Department of Energy and its predecessor agencies. Based on accident and incident files in the Office of Operational Safety and on supplementary responses, 587 incidents including over 100 fires are analyzed.

Tables and figures, with supplementary narratives discuss fire experience by various categories such as number of heads operating, type of system, dollar losses, failures, extinguished vs. controlled, and types of sprinkler heads. Use is made of extreme value projections and frequency-severity plots to compare past experience and predict future experience.

Non-fire incidents are analyzed in a similar manner by cause, system types and failure types. Discussion of "no-loss" incidents and non-fire protection water systems is included.

The report ends with the author's conclusions and recommendations and appendices listing survey methodology, major incidents, and a bibliography.

Forward

For over 30 years, the automatic sprinkler system has been the basic instrument of fire protection in those laboratories, reactors, enrichment plants, weapons facilities and engineering research and development activities now operated for the Department of Energy.

In recent years, new types of fire protection systems have proliferated, new requirements for emergency forces have been imposed and the philosophies of safety analysis and risk projection have enjoyed major advances. At the same time, there have been some articles questioning the historic efficiency of the sprinkler system and urging more "sophisticated" approaches to the admittedly complex problem of loss protection.

This study provides an in-depth look at the history of the automatic sprinkler system in DOE, from the standpoint of both its effectiveness and its reliability. Although DOE has been, and will continue to be, a leader in the application of new programs and new systems, it is clear that our continued reliance on the automatic sprinkler system as the basic fire protection system, is amply justified.

D. E. Patterson
Acting Director
Office of Operational Safety

Executive Summary

Since the founding of the Atomic Energy Commission in 1947, the automatic sprinkler system has been accepted as the principal fire protection system in all types of facilities. The sprinkler system has been routinely installed in the conventional laboratory, office, manufacturing and storage facilities operated by the AEC and its successor agencies. In addition, sprinklers are the most common protection system installed in computers, reactor control rooms, electrical equipment rooms and areas where the principal hazard is from nuclear criticality or radioactive contamination.

Although there have been a number of individual incidents where the sprinkler system undoubtedly prevented much larger losses, including one that probably repaid the cost of every sprinkler system installed in the agency's history, installations have been made more on the basis of hazards analyses and comparable industrial and insurance company experience than on actual agency experience.

Paradoxically, the very success of the fire protection program has prevented the accumulation of usable data prior to this report. The cumulative fire loss ratio for the entire Department of Energy, since 1947, is less than 1¢ for every $100 of value ($100 per million), or about one-third of the loss rate for the "highly-protected risk" class of insurable property. Since 1975, there have been an average of 26 reportable (over $1000 damage) fires per year, including vehicles and brush fires, despite the fact that DOE possesses over $50 billion in plant and equipment values. In fact, since 1970, there have been only two years in which the annual fire loss ratio exceeded 0.25¢ per $100 of value. Thus, the very success of the program prevented accumulating enough instances to provide a statistical confirmation of the value of the individual systems.

In 1980, a special effort was inaugurated to collect as complete a record of sprinkler operations as possible. All records were reviewed and additional data solicited from the department's contractor-operated sites. As a result, nearly 600 incidents were assembled and analyzed for this report.

The value of the automatic sprinkler system has been confirmed. As the body of the report demonstrates:

> The loss from fire in a sprinklered building is about one-fifth of the loss in an unsprinklered building--despite the fact that only the low loss potential facilities are not sprinklered.
>
> There has been no loss of life due to fire in a sprinklered building.
>
> The sprinkler system is more than 98 percent effective in controlling or extinguishing fires.
>
> About one-third of all fires were completely extinguished by the operation of a single sprinkler head.

If the purpose of this report was only to confirm the value of the automatic sprinkler system as a fire protection tool, it would serve little purpose. The above conclusions are hardly surprising to the fire protection community in general, and the Department of Energy needs no convincing as to the value of sprinklers. More importantly, the large number of non-fire incidents involving sprinkler systems has allowed some statistical proof of their reliability to be presented; proof that has been all too rare until now. Since the last bastion of resistance to sprinkler installations involves fears of reliability in general, and water damage in particular, the following observations may be the most important to have been drawn from the study:

> The chance of a sprinkler head failing is about one in a million per year.
>
> The chance of any damage to, or from, a sprinkler system is about one per year for every 800 systems;--and nearly half the incidents were so slight that the damage to, or from, the system was negligible.
>
> Sprinkler systems are more reliable than non-fire protection water systems. Both the frequency of losses and the mean dollar loss from sprinkler incidents is about one-half of that from other water systems.
>
> On the basis of loss projection techniques, the mean loss from a fire controlled by sprinklers is fifty times the mean damage to, or from a sprinkler system accident.
>
> On the basis of the actual experience, the damage resulting from the presence of a sprinkler system is less than one percent of the fire damage that will result if the system is not present.

The final, and most conclusive proof of the value of sprinkler systems is missing from this report. While the protection of life and property are as important to the programs of the Department of Energy as they are to any private or government organization, the unique energy supply and national defense functions make program continuity the most vital aspect of the Department's fire protection programs. That aspect would not have been possible without the automatic sprinkler system.

Walter W. Maybee

Walter W. Maybee
Manager, Fire Protection

PART A FIRE EXPERIENCE

A1 Background - Sprinklers in AEC-DOE

The United States Department of Energy, as of 1980, owned over 6000 buildings comprising some 100 million square feet of area and occupied by over 140,000 federal and contractor employees. The majority of the major facilities had their origins in the World War II Atomic Bomb project and DOE accident data begins with the Manhattan Engineering District (MED) of 1943, the bomb project agency.

The U.S. Atomic Energy Commission (AEC) 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. Beginning in the 1950's, the early AEC laboratories grew into the National Laboratory system of today; a weapons testing site was acquired in Nevada, new gaseous diffusion plants were opened, major high-energy physics accelerator sites were built, and many reactor concepts were developed and prototypes built at the new National Reactor Test Site in Idaho.

Though the total investment in the bomb effort during World War II was a then-astronomical $2 billion, the estimated replacement value of all AEC-owned facilities at the end of 1975 was in excess of $30 billion.

The AEC ceased to exist in 1975; the Nuclear Regulatory Commission (NRC) was formed from the regulatory staff of the AEC, and the development staff was combined with some research centers operated by the Bureau of Mines to become the Energy Research and Development Administration (ERDA). Similarly, in 1977, ERDA was combined with some nonnuclear regulatory agencies and naval petroleum reserves and power marketing agencies (such as Bonneville Power Administration) to become the Department of Energy (DOE). The replacement value of DOE plant and equipment as of the end of 1980 was in excess of $54 billion.

When the AEC was formed in 1947, it inherited the programs and facilities which had been created solely as a crash program to develop an atomic bomb. Even though many buildings were both substantially built and provided with automatic fire 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, California, used 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 2,000,000 sq.ft. building with a General Services Administration warehouse.

The background and experience of the first-generation of AEC fire protection engineers led them naturally to adaptations 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. Since the automatic sprinkler system is basic to the "improved risk" concept of fire protection, retrofit sprinkler programs were already being applied in the 1950's.

The gaseous 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 were 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, noncombustible construction, with insulated metal deck roofs, and total over 20 million square feet in area, the largest having mearly 3 million square feet under one roof.

At all three plants, on site fire departments supplemented the extensive fire protection systems. Sprinkler protection was provided for offices, laboratories, shops, transformers, and cooling towers. Sprinklers were not installed in the diffusion buildings themselves because of the lack of proven fire hazards, limited combustible contents, and supposedly noncombustible construction.

A fire at the Paducah Plant in 1956 caused 2.1 million dollars damage and demonstrated the fire potential of the insulated, metal-deck roof. Following the fire, the hazards evaluation project was intensified. In addition to the AEC evaluations, the process building hazards were surveyed by management-level, security-cleared personnel of both the Factory Insurance Association (FIA) and the Factory Mutual Research Corporation (FMRC), and the evaluation of sprinkler criteria for the oil hazard was done by the FMRC. Full automatic sprinkler protection was chosen as the best of several alternatives, and between November 1957 and June 1961, sprinkler systems were installed in all the plants at a cost of $17,626,000 (an underrun, incidentally, of nearly $900,000 from the authorized cost).[1]

In addition to being completed at a cost considerably under the authorized funding, the sprinkler installation project, with the Grinnell Corporation as principal mechanical subcontractor, established the all-time National Safety Council record of over 3 million injury-free man-hours in the public utility construction category. (The record is 3,075,079 injury-free man-hours.) This was done despite the difficulties of installations in the high-heat areas and roof heights of 85 feet.

In 1962, the second Paducah fire occurred, in a building that was now sprinklered (see story in Appendix D). The loss totalled $2,900,000 (most of the damage being due to the original explosion), 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.

Sprinklers continued to be retrofitted to existing buildings and most new facilities were fully sprinklered.

In 1969 the second major unsprinklered fire occurred, this at the Rocky Flats plutoniun plant.[1] The loss of $26,473,000 (including $9,999,000 decontamination costs) prompted a major upgrading program at all sites, and several new programs, including an independent appraisal program and additional fire protection engineer staffing. For sprinkler systems, this resulted in a mean of over 100 new systems per year being installed in existing facilities every year since 1970. In addition to the sprinkler systems, in the same period there were installed 525 halon systems, 25 CO_2 systems, 12 foam and 8 dry chemical systems.

Because of the additions to existing buildings and the large number of new buildings with installed sprinklers, it is not possible to cite an exact figure for the number of sprinkler systems in DOE. The problem is further complicated by the number of sites that no longer exist, sprinklered buildings that have been demolished, and systems that have been modified over the years. Data on the number of systems at sites submitting additional incidences for this report was collected and forms the basis for the frequency-reliability data in these summaries. The data is included as Appendix B to this report.

[1] Review of Fire Protection in the Nuclear Facilities of the Atomic Energy Commission 1947-1975 by W. Maybee, Nuclear Safety Volume 20, No. 3, May-June, 1979.

A2 Cumulative Sprinkler Performance

In 115 fires involving sprinkler systems in DOE facilities since 1952, the sprinklers were successful in controlling or extinguishing the fire in 113, or 98.3 percent of the incidents. This compares favorably with the 95 percent satisfactory performance reported by the NFPA,[1] and is close to the 99.1 percent favorable experience recorded by the Australian Fire Protection Association.[2]

Figure A2 shows the comparative experience by number of sprinkler heads operating. Although DOE has the distinction of one fire involving over 2000 heads in a successful operation, the majority of fires were controlled or extinguished by the operation of only one sprinkler. Three quarters of all fires involved not more than two heads and a maximum of three heads were involved in 83 percent of the cases.

The favorable DOE experience is much closer to the Australian-New Zealand experience than the NFPA's reported U.S. experience. The reasons for the better DOE performance parallel those given for Australian-New Zealand experience, namely:

1. The reporting is more complete. The DOE summary is made up of all fires reported to DOE Headquarters since 1952. Prior to 1975, this included all fires with a loss exceeding $50 ($1000 after 1975). In addition, most DOE sites supplied additional data on sprinkler fires over the past five to twenty years that included many one-head operations and negligible losses (see Section A-12). The additional data was supplied by facilities accounting for over 70 percent of DOE's total values. With perfect reporting, it is believed the experience would even more closely approximate the Australian-New Zealand experience.

2. All systems reported had waterflow alarms. In addition, the vast majority reported directly to an on-site emergency organization.

3. Inspection and maintenance of sprinkler systems is undoubtedly better than the U.S. average. In addition to the NFPA fire protection standards being mandatory DOE standards, some 27 DOE sites have on-site fire and emergency services and nearly all sites exceeding $25 million in replacement value have one or more professional fire protection engineers on the staff.

4. Sprinkler valve controls, including electrical supervision, are probably more extensive, and effective, at DOE facilities than at the average U.S. sprinklered property. Although the closed-valve failure (1 out of 2 cases) equals the 50 percent national failure rate for failures due to the sprinkler system (as opposed to occupancy and exposure failures), the single DOE loss occurred in a non-government-owned facilityin 1958 and involved a dust collector in which a cold-weather valve was closed (Feb 21 fire).

5. The average age of DOE sprinklers is probably less than the national average. Only 10 of the fires were definitely known to involve old style (pre 1954) sprinkler heads. Sprinkler systems were installed in the Manhattan Engineering District facilities (1943-1947) but the major sprinkler retrofit programs began after the 1962 Poducah fire and a 1969 Rocky Flats fire.* In addition, a number of older facilities are no longer DOE facilities, and a fair number of old systems (particularly in cooling towers), have been upgraded.

While the number of DOE sprinkler incidents results in less statistical validity than the comparison curves, the experience does cover a wide range of occupancy groups and system types over a considerable number of years. Although only a few, limited occupancy studies,[3] have indicated better performance, the author concludes that the DOE experience is closer to the true performance than that reported for the U.S. as a whole and that the Australia-New Zealand experience is closest to the true performance record of automatic sprinkler systems.

*Over 50 systems were installed at Los Alamos, and probably another 50 at Hanford, including one-story offices. Most were temporary frame buildings long since demolished.

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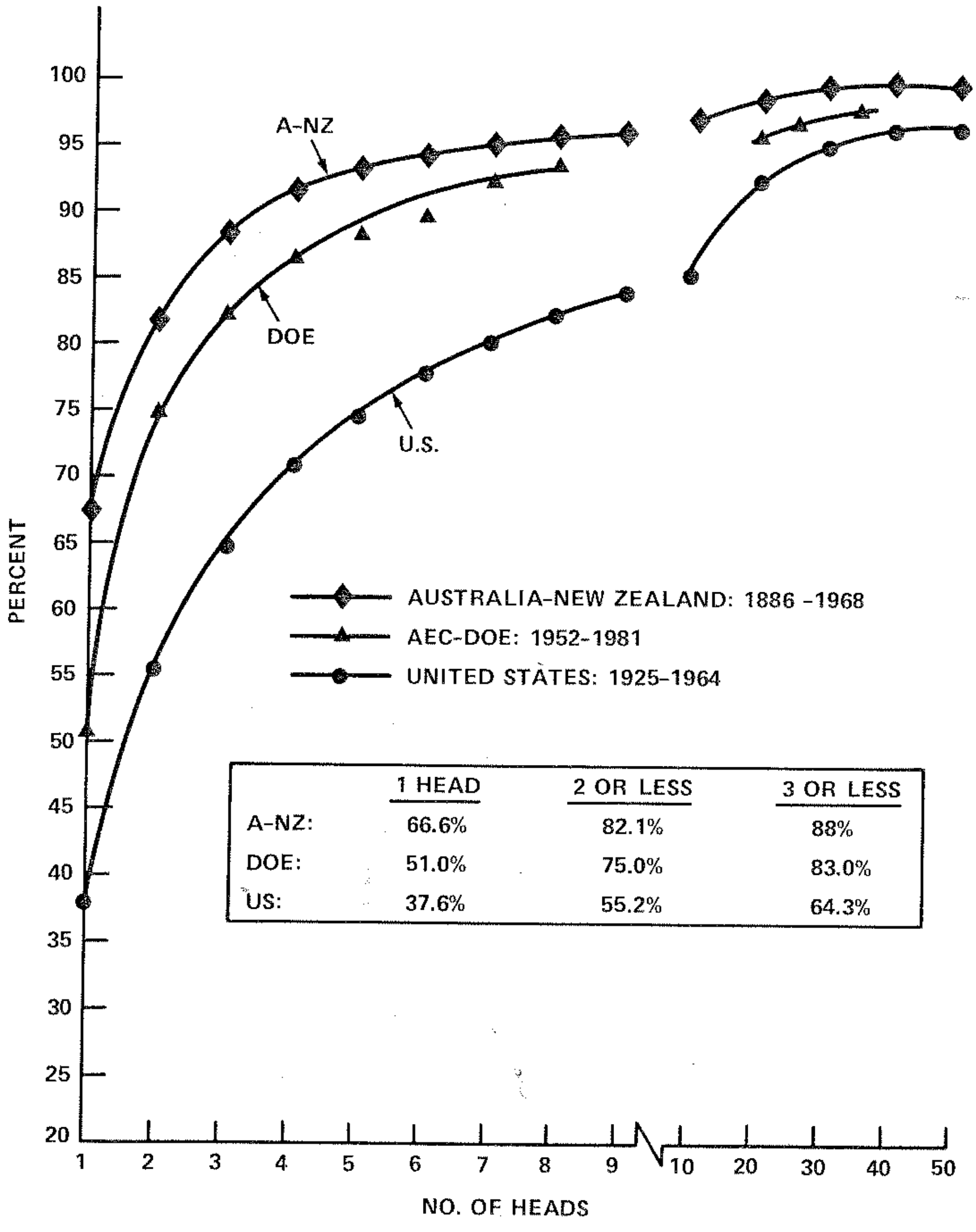
[1]Fire Protection Handbook, 14th Edition, NFPA, page 14-4. The experience covered 117,770 fires in sprinklered buildings.

[2]Fire Automatic Sprinkler Performance in Australia and New Zealand, 1886-1968, H. W. Marryatt, Australian Fire Protection Association 1971. The experience covered 5,734 fires.

[3]NFPA Fire Journal, November 1972. In 41 fires, 97.5 percent were controlled by three or less heads in high-rise occupancies. In 661 fires, performance was 98.9 percent satisfactory.



	1 HEAD	2 OR LESS	3 OR LESS
A-NZ:	66.6%	82.1%	88%
DOE:	51.0%	75.0%	83.0%
US:	37.6%	55.2%	64.3%

FIRES CONTROLLED OR EXTINGUISHED
CUMULATIVE NO. OF HEADS OPERATING – %

A3 Performance by Type of System

Chart A3 shows performance for the major types of sprinkler systems according to the number of heads operating. Due to the small number of systems, other than wet pipe, that are included in the reports, it is not statistically valid to draw conclusions.

For the wet pipe systems, the experience conforms to national experience - namely, that wet pipe sprinkler systems are the most effective. Comparing the experience of all systems, combined, with that for wet pipe systems only, we have:

Cumulative Heads	Percent Controlled or Extinguished by	
	Wet Pipe	All
1	51.1%	51.0%
2	75.6%	75.0%
3	84.4%	83.0%
6	92.2%	89.1%
7	94.4%	92.1%
20	95.6%	99.0%

Chart A3 demonstrates the truth of the general assumption that the greater the number of sprinkler heads opened in a fire, the less chance that the sprinklers will extinguish the fire unaided. In fact, with the exception of a single fire involving eight heads, the one-head operation is the only category in which more fires were completely extinguished by the sprinklers alone, rather than by a combination of the sprinkler action and portable extinguishers or hose streams.

Note that one of the failures involved a single head. This was a one-head system (in a dust collector) in which the valve was closed (a cold weather valve mormally closed in February).

There is a gap in DOE experience, with no reported fires involving more than 8, or less than 20 heads. The cumulative total up to 8 heads includes 93 percent of all the fires in which the number of heads operating were known. The 6 incidents involving 20 or more heads were all special cases (see Appendix C). This leads to the interesting conclusion that water supplies are far less important than complete sprinkler coverage. There have been no cases in DOE where inadequate water supply was a factor, and numerous cases where lack of sprinklers resulted in significant loss. Since 93 percent of DOE fires are controlled by 8 heads or less, and the discharge from 1 head, even at 100psi is little more than 50gpm per head, 400gpm flows would be adequate 93 percent of the time! While such a conclusion hardly agrees with fire protection practice, it certainly justifies budget priorities directed towards obtaining complete sprinkler coverage before any additional improvements to water systems are scheduled. Except for well defined special hazards occupancies where flow requirements can be related to actual fire test data, secondary water supplies and increases in available water flow appear to be far less important than insuring adequate and reliable sprinkler systems.

A3-1

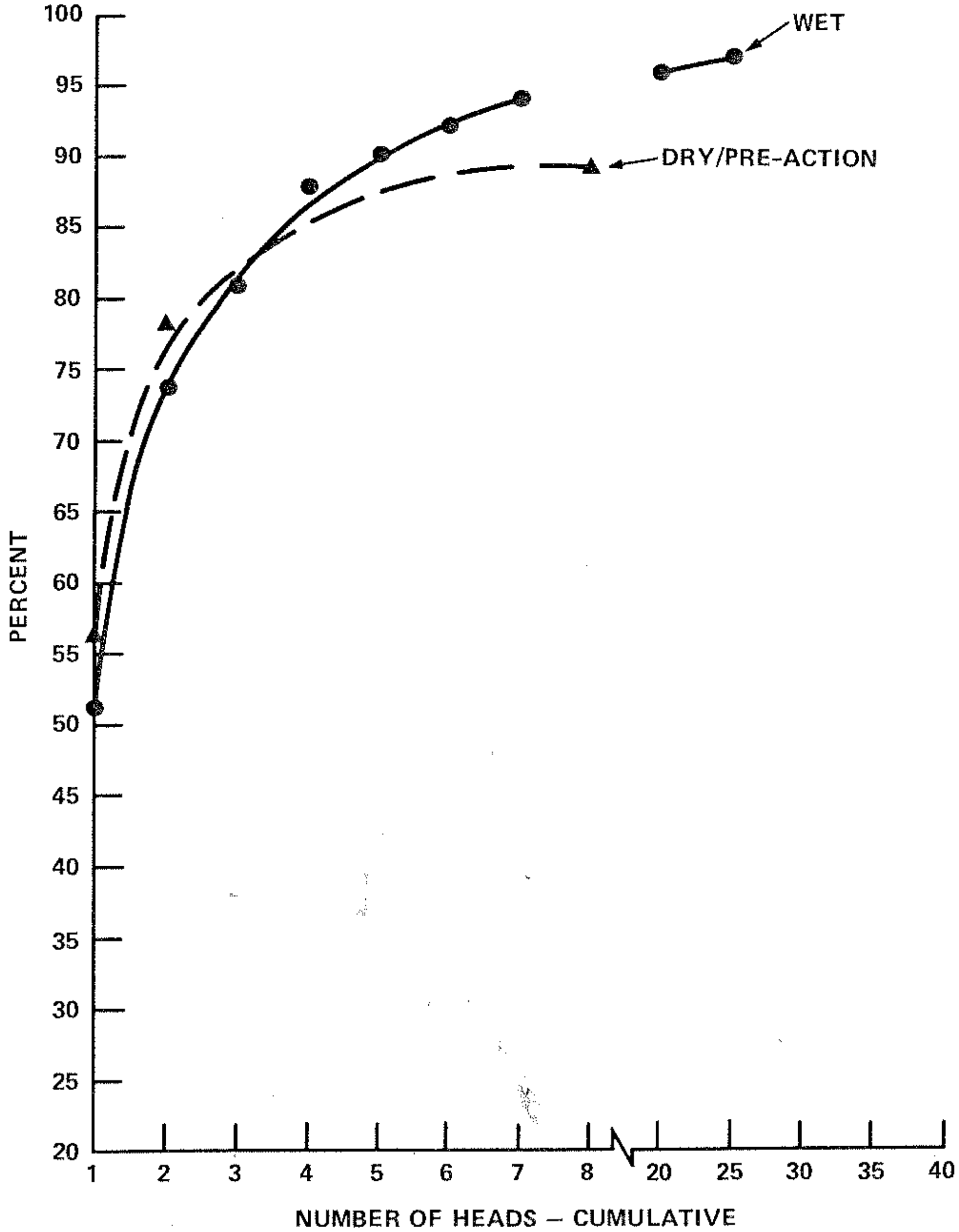
Automatic Sprinkler Performance

No. of Heads	Wet Systems			Dry or Preaction Systems			TOTAL		
	Controlled	Extinguished	Failed	Controlled	Extinguished	Failed	Controlled	Extinguished	Failed
1	20	26	1	3	2	0	23	28	1
2	13	9	0	1	1	0	14	10	0
3	7	1	0	0	0	0	7	1	0
4	2	2	0	0	0	0	2	2	0
5	2	0	0	0	0	0	2	0	0
6	1	0	0	0	0	0	1	0	0
7	2	0	0	1	0	0	3	0	0
8	0	0	0	0	1	0	0	1	0
20	1	0	0	1	0	0	2	0	0
25	1	0	0	0	0	0	1	0	0
34	1	0	0	0	0	0	1	0	0
149	1	0	0	0	0	0	1	0	0
2,431	1	0	0	0	0	0	1	0	0
Unknown	2	1	0	0	0	0	2	1	0
Subtotal	54	39	1	6	4	0	60	43	1
Deluge	--	--	--	7	3	1	7	3	1
Total	54	39	1	13	7	1	67	46	2

A3-2

Sprinkler Performance by Type of System
(Percent figures to nearest 1 Percent)

Type	Extinguished	Percent	Controlled	Percent	Failed	Percent	Total	System % of Total Fires	% of Total Fires by System: Ext.	Cont.	Fail.
Wet	37	38%	53	58%	1	1%	91	79%	32%	46%	1%
Dry	1	20%	4	80%	0	0%	5	4%	1%	3%	0%
Preaction	3	100%	0	0%	0	0%	3	3%	3%	0%	0%
Deluge	3	27%	7	64%	1	9%	11	10%	3%	6%	1%
On-Off or Multicycle	0	0%	2	100%	0	0%	2	2%	0%	2%	0%
Anti-freeze	1	100%	0	0%	0	0%	1	1%	1%	0%	0%
Unknown	1	50%	1	50%	0	0%	2	2%	1%	1%	0%
TOTAL	46	40%	67	58%	2	2%	115	100%	40%	58%	2%



WET SYSTEMS VS. DRY AND PREACTION SYSTEMS
CUMULATIVE PERFORMANCE

A4 Fires Controlled vs. Extinguished

Table A4 lists the number of fires and dollar losses according to the number of sprinklers operating. The table further divides fires into "controlled" or "extinguished" categories. Fires were considered to be extinguished only when no other action was taken by employees or fire departments (no extinguishe or hose used).

The table does not include the $2.9 million Paducah fire as this was unique in that over 2,000 heads operated and the dollar loss exceeded all other instances combined.

Utilizing the "Total" line, the table reads as follows:

> Of 64 fires controlled by sprinklers, the mean loss was $17,278 and the maximum was $243,000. For the 45 cases in which sprinklers had completely extinguished the fire, the mean loss was $3,473 and the maximum $24,000.

The effect of the large loss is demonstrated by the comparison between "controll and "extinguished" and by the comparisons by number of heads operating in either category. Note the rough comparison between the percentage of fire incidents and percentage of dollar loss except for strong differences at both ends of the scale.

For single head fires, 36 percent of the "controlled" fires involved only one head, and these 23 fires accounted for only 2 percent of the dollar loss. The single-incident losses involving 25 or more heads each constituted about 2 percen of the number of "controlled" incidents, but the losses were 18 and 22 percent of the total.

The discrepancy from the above rule is the 34 head fire which amounted to only a $502 loss. This was the smouldering fire in a rubberized packing material (see Appendix C) where the total value at risk was quite small.

The number of incidents in which the fire was extinguished (45 out of the 109 items)* is somewhat surprising in view of the fact that all systems had water-flow alarms and most are direct-connected to an on-site fire department. Brigade and emergency training is also quite extensive at most sites. In effect, DOE sites would be expected to have prompter fire department response than the average industrial plant, and employees would be expected to be more ready to use portable extinguishers than the U.S. average. The fact that the sprinklers alone had completely extinguished the fire in nearly half the cases is a further tribute to their effectiveness.

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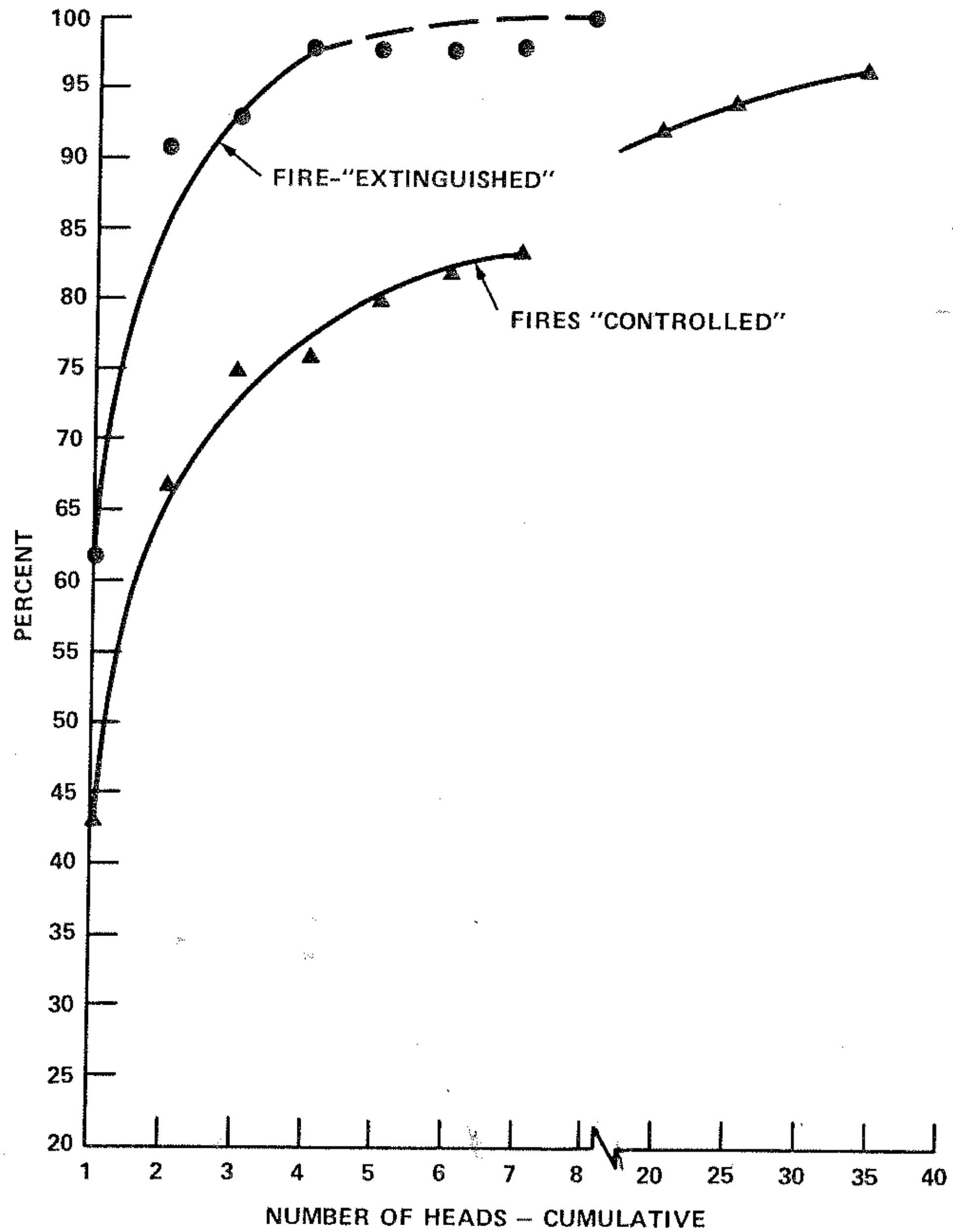
*Different charts may have different totals since not all the data items were known for every incident report.

FIRES CONTROLLED VS. EXTINGUISHED

HEADS	CONTROLLED NO.	CONTROLLED $	CONTROLLED % NO.	CONTROLLED % $	MEAN$	MAXIMUM$	EXTINGUISHED NO.	EXTINGUISHED $	EXTINGUISHED % NO.	EXTINGUISHED % $	MEAN$	MAXIMUM$
1	23	26,752	36	2	1,163	5,500	30	63,705	67	41	2,124	23,000
2	15	130,187	23	12	8,679	50,000	8	5,278	18	3	660	2,117
3	6	42,310	9	4	7,052	27,060	0	0	0	0	0	0
4	2	41,050	3	4	20,525	41,000	2	6,980	4	5	3,490	6,730
5	2	7,395	3	1	3,698	7,095	0	0	0	0	0	0
6	1	43,400	2	4	43,400	43,400	0	0	0	0	0	0
7	3	109,493	5	10	36,498	91,500	0	0	0	0	0	0
8	0	0	0	0	0	0	1	20,000	2	13	20,000	20,000
20	2	76,030	3	7	38,015	76,030	0	0	0	0	0	0
25	1	200,104	2	18	200,104	200,104	0	0	0	0	0	0
34	1	502	2	0	502	502	0	0	0	0	0	0
149	1	243,000	2	22	243,000	243,000	0	0	0	0	0	0
Deluge	7	189,545	11	17	26,506	155,000	4	60,300	9	39	15,075	24,000
TOTAL	64	1,105,768	100	100	17,278	243,000	45	156,263	100	100	3,473	24,000



"EXTINGUISHED" VS. "CONTROLLED"
CUMULATIVE PERFORMANCE

A5 Overall System Performance, Extinguished vs. Controlled

Table A5 lists systems by their overall performance in terms of either extinguishing or controlling the fires.

For the most prevalent case, wet pipe systems, the table shows that 37, or 41 percent of the 91 total wet pipe system fires were completely extinguished by the system. In another 53, or 58 percent of the total wet pipe cases, the fire was controlled, and there was one failure.

The final columns show that the 91 wet pipe cases were 79 percent of the total number of sprinkler system cases and that the 37 instances of complete extinguishment constituted 32 percent of the total cases. In other words, about one-third of all the sprinkler fires in the study were cases where a wet pipe system completely extinguished the fire.

With dry systems, the fire was extinguished in 20 percent of the cases or about half as often as with wet pipe systems. While dry systems are expected to be less effective than wet systems, due to the time lag for water to reach the head after it fuses, some of the difference may be due to the presence of on-site fire departments at major DOE facilities. The dry systems may have been equally capable of extinguishing the fires that occurred in their areas, but the fact that water had been flowing for less time allowed the fire department to apply extinguishers or booster hose, resulting in a "controlled," rather than "extinguished" classification.

The 100 percent extinguishing success for preaction systems tends to belie the above assumption, since the separate alarm system for a preaction system should result in even faster fire department response. However, the 3 fires included a $20,000 reactor hot cell which precluded manual assistance, (see Section A8), and the laundry trailer fire in which 1 head extinguished the fire before the fire department arrived (see Section A8).

Other system incidents were too few for the statistical breakdowns to have any validity.

Sprinkler Performance by Type of System

(Percent figures to nearest 1 Percent)

Type	Extinguished	Percent	Controlled	Percent	Failed	Percent	Total	System % of Total Fires	% of Total Fires by System		
									Ext.	Cont.	Fail.
Wet	37	41%	53	58%	1	1%	91	79%	32%	46%	1%
Dry	1	20%	4	80%	0	0%	5	4%	1%	3%	0%
Preaction	3	100%	0	0%	0	0%	3	3%	3%	0%	0%
Deluge	3	27%	7	64%	1	9%	11	10%	3%	6%	1%
On-Off or Multicycle	0	0%	2	100%	0	0%	2	2%	0%	2%	0%
Anti-freeze	1	100%	0	0%	0	0%	1	1%	1%	0%	0%
Unknown	1	50%	1	50%	0	0%	2	2%	1%	1%	0%
TOTAL	46	40%	67	58%	2	2%	115	100%	40%	58%	2%

A6 Dollar Losses by Type of System

Tables A6-1 and A6-2 list the dollar losses in sprinkler fires. Again, the distorting affect of the single largest loss is evident. Deletion of the largest loss reduces the mean of more than 100 losses by two-thirds.

The overwhelmingly predominant type of system, wet pipe, with 78.4 percent of the number of incidents also resulted in 85.4 percent of the dollar loss (or 68.4 percent if the largest loss is omitted).

Wet pipe systems are the preferred types in DOE facilities for simplicity and reliability. While there is no breakdown of their fraction of the total number of systems installed, they are believed to equal or exceed the 79 percent represented in the losses.

The mean loss for each system is included. Due to the small number of other than wet pipe systems, mean loss figures have little significance. However, the deluge and multicycle systems show a mean loss considerably above the average. The multicycle results from 2 extremes, a "no-loss" fire, and a $91,000 fire. The deluge mean, even deleting the major deluge fire, is still well above the average loss but is to be expected from the type of hazards protected by deluge systems.

The single antifreeze incident involved a vacant shed in the rear of an old, leased office building. The shed was provided with sprinklers on an antifreeze loop fed from the office building wet pipe system. Vandals broke into the shed and tried to burn the insulation off some stolen copper wire. A single head extinguished the fire with no government loss.

Fire Losses by Type of Sprinkler System
(All Sprinkler Fires Including Failures)

System	$Total	% of Total	No. of Fires	% of Total	$Mean	$Maximum	$Minimum
Wet	3,777,683	85.4%	93	78.8%	40,620	2,900,000	0
Dry	42,350	1.0%	5	4.2%	8,470	38,000	0
Preaction	20,325	0.5%	3	2.5%	6,775	20,000	25
Deluge	487,645	11.0%	11	9.3%	44,331	244,800	395
On-Off or Multicycle	91,500	2.1%	2	1.7%	40,750	91,500	0
Anti-freeze	0	0%	1	0.8%	0	0	0
Unknown	2,568	0.1%	3	2.5%	1,284	1,300	0
Total	$4,422,071	100%	118	100.0%	$33,475	$2,900,000	0

Fire Losses by Type of Sprinkler System
(Excluding Paducah Fire and Two Failures)

System	Total	% of Total	No. of Fires	% of Total	$Mean	$Maximum	$Minimum
Wet	865,683	68.4%	91	79.1%	9,513	243,000	0
Dry	42,350	3.3%	5	4.4%	8,470	38,000	0
Preaction	20,325	1.6%	3	2.6%	6,775	20,000	25
Deluge	242,845	19.2%	10	8.7%	24,285	155,000	395
On-Off or Multicycle	91,500	7.2%	2	1.7%	40,750	91,500	0
Anti-freeze	0	0	1	0.9%	0	0	0
Unknown	2,568	0.2%	3	2.6%	1,284	1,300	0
Total	1,265,271	100.0%	115	100.0%	11,002	243,000	0

A7 Sprinkler Failures

There were only two failures in the study. These are described below.

At a Uranium processing plant, on February 21, 1958, pyrophoric dusts spontaneously ignited in an electrostatic dust collector system. The sprinkl involved was controlled by a cold weather valve and was off at the time. The total loss was $12,000.

The other failure occurred in the transformer yard at a gaseous diffusion pla A large power transformer failed and ruptured, resulting in ignition of the 17,000 gallons of contained oil. The transformers were protected by deluge systems in which the pneumatic actuators dropped a weight in the releasing mechanism box. The weight, sliding down a guide rod, hits a trip lever, discharging the system. The guide rods had been replaced in March of 1958 after some had shown signs of corrosion.

On December 13, 1963, the subject transformer failed, breaking a 3 inch sprin line in the process. The deluge system did not operate and the manual releas did not activate the system. Other systems worked and there was no exposure damage to adjoining transformers. Most of the $244,800 loss was due to the original rupture so, ironically, the system failure had little impact on the amount of the loss.

After the fire, it was discovered that the guide rod in the release mechanism was slightly bent, slowing the weight so that it did not have enough impact to trip the system when it hit the trip lever. The manual release had no eff since the weight was already released when the trip was pulled.

After the fire, 25 other deluge systems in the transformer yard were tested a the same problem was found on 1 other. All were subsequently repaired.

There had been two other occasions at the same plant before 1956 in which lea in 100,000 KVA transformers had ignited and been successfully contained by th deluge systems.

A8 Sprinkler Fires By Occupancy

Tables A8-1 and A8-2 tabulate the sprinkler fire experience by occupancy categories. Because of the drastic effect of the Paducah fire, Table A8-1 includes all data, while Table A8-2 repeats the data except that the Paducah fire and the two failures (See Section A7) have been deleted.

Utilizing the laboratory occupancy on Table A8-1, the table shows that there were a total of 23 fires involving sprinklers in laboratories. These 23 fires constituted 19.8 percent of the total number of sprinkler fires. The total loss from the 23 fires amounted to $86,462, which was 2 percent of the total losses for all occupancies. The mean loss in laboratories was $3,759, but the spread was from a reported "no loss" to maximum of $43,400. Of the 23 losses, 22 or 99.6 percent were controlled or extinguished by only 1 or 2 sprinklers.

Deleting the effect of the single Paducah (which accounted for over one-half the total loss) and the two failures, the laboratory fire data is unchanged, but the percent of total incidents represented by the 23 fires has changed from 19.8 percent to 20.4 percent and the dollar loss changes from 2 percent of the total to 6.8 percent.

In terms of successful sprinkler operation (disregarding single-incident occupancies) the electrical equipment rooms, laundry and computer fires all involved only one or two heads, as did the paper shredders and filter bank fires. Least successful, in terms of opening more than two heads were fires in plating shops, mechanical equipment rooms, gloveboxes and H.E. processors. Half or more of the fires in these occupancies opened more than two sprinklers.

In terms of mean dollar loss, fires in manufacturing facilities, mechanical equipment rooms, laundries, gloveboxes and H.E. processing all averaged less than $2,000 per fire. The only occupancies averaging more than $10,000 per fire were plating shops, hot cells, electrical equipment rooms and garages. The highest category, garages, is distorted by the single, $243,00 fire (see Appendix D). The other two garage fires totaled only $502.

None of the data in these tables should be used indiscriminately. The small number of total fires, and the large number of occupancies makes any averages unreliable. For instance, the only two computer fires were $9,000 and $574. The mean thus has little predictive value, expecially in view of the fact that some DOE computer rooms exceed $25 million in value in a single fire area.

The effect of the rare, large loss fire is best illustrated by the Gaseous Diffusion Plant experience. While the plants have been in operation for nearly 30 years, the single large loss changes the mean loss by an order-of-magnitude. As emphasized elsewhere, predictive techniques must utilize more sophisticated means than merely relying on past experience. These techniques are emphasized in DOE's Management Oversight and Risk Tree (MORT) analysis courses, the Accident/Incident Investigation Course and the Risk Assessment course, and in the series of System Safety Development Center monographs.

Several occupancy groups are discussed further below.

Cooling Towers. Cooling towers serve throughout DOE 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 in the final stage of the motor-compressor cooling systems at 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 the 1950s in accordance with the major insurance industry thinking of the time. (The NFPA cooling tower standard was not adopted until 1959). These systems served well during several fires, 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 outrace 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 up-rating program for all three diffusion plants. An idea of the size and number of towers involved is shown by the fact that the sprinkler system upgrading alone cost over $3 million.

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. The damage amounted to several thousand dollars in each case since the deluge systems could not be activated 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 fire 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 the AEC. The other incident occurred at a major accelerator facility under construction in 1964. The tower burned in a fire ignited by a welding spark, and two of the three cells were lost, but it was still the property of the construction contractors at the time of the fire, so no government dollar loss was incurred. 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, the installation of which was not complete at the time and therefore not a factor in the fire.

Computers. Computers have always been essential to DOE operations, and their use has expanded greatly with time. By 1975 the AEC had 3485 computers and central processing units valued at nearly half a billion dollars. Of these, 324 were valued at over $200,000 each.

The 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.

The 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 standard 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).

Most DOE computer facilities are sprinklered throughout. Also, under floor protection is provided in most facilities with Halon predominating, although there are some CO_2 systems and even some sprinklers under floor.

The two computer fires in this study occurred in 1978 and 1980. The major loss was from an internal short, extinguished by one sprinkler head. The other originated in a canteen alcove and was extinguished by two sprinkler heads.

While a number of internal defect computer fires have occurred, they were all extinguished by operators. There have been no reported underfloor or tape vault fires.

Nuclear Reactors. Nuclear reactors are distinguished by their scarcity in this study despite their number and widespread utilization of sprinkler system protection. Chapter VI, "Safety of DOE-Owned Reactors" of the basic DOE Safety Order, identifies 86 reactor and criticality experiment facilities under DOE ownership.

Fire protection provided for reactors was always similar to that provided for other facilities. Although the AEC supported such activities as the development of generic "good practice" documents by the Atomic Energy Committee of the NFPA, no reactor-specific requirements were generated. Indeed, none were considered necessary.

The accident record AEC history (1947-1975) supported the AEC's position. Of some 18 major losses (over $50,000) in reactor facilities, most were due to contamination cleanup or loss of heavy-water moderator. Half of the nearly $9,000,000 total was the result of the 1961 excursion in the SL-1 reactor as well as the only fatalities (3) in the history of reactor operations. Interestingly enough, even though there was no fire at SL-1, it was the activation of a fire detector that brought the first emergency response, the fire department.

When several test reactor buildings were found to have combustible, albeit metal deck, roofs, they were provided with automatic sprinklers. Further, although AEC reactors were seldom comparable to commercial reactors, a 1974 survey disclosed that protection was more extensive at AEC facilities than at most commercial facilities. As an example, over half of 43 control rooms were provided with complete automatic fire extinguishing systems, mostly in the form of automatic sprinklers -- this, in addition to Halon, CO_2, portable extinguishers, and extensive automatic fire alarms systems. Also, all the reactors were located at sites that had full-time, on-site, AEC-or contractor-operated fire departments.

One fire did occur in an organic-moderated reactor hot cell area in 1962. Eight heads on a preaction system extinguished the organics fire for a loss of $20,000.

Plating Shops. Plating operations accounted for almost 7 percent of the number of sprinkler fires and 4 percent of the dollar loss. The accident reports reveal an almost standard ignition scenario. An empty or lowered-liquid level tank exposes a plastic lining, or ductwork to a heating element.

Lack of, or failure of heating controls leads to ignition of the combustible lining or ducts. The high mean dollar loss, and larger number of sprinklers operating, is due to the fires frequently involved, or spreading in ductwork.

There is one automatically extinguished plating tank fire not included. The fire melted a solder connection on a water line over the tank and the water extinguished the fire.

Hot Cells. "Hot Cells," "Caves" and "Canyons" are heavily shielded facilities for handling large items and/or highly radioactive processes. They range up to the size of football fields. While combustible contents are generally very low (combustible process liquids are usually in enclosed sub-cells with gaseous protection systems), access during operations is impossible and supplementary systems are provided. They range from remote extinguisher manipulators or plug-in extinguisher piping to full scale deluge systems, both manual and automatic. Water collection systems are usually provided to contain contaminated water and the spread of contamination is usually a major component of the loss (of course the contamination is generally much less than if the fire had burned itself out; the water spread is two-dimensional, fire is three dimensional).

The three fires in this study include a 1954 neptunium ion-exchange column fire in which the deluge system extinguished the $21,000 fire; a 1964 spontaneous ignition $21,000 fire in which the deluge system also extinguished the fire and a 1967 fire involving a manual deluge system in which the loss was $195,000. The contamination potential is demonstrated by a 1959 accident systems trip which required $1400 in cleanup costs.

Filter Banks. High-efficiency particulate air filters are used in a number of industries requiring ultra-clean environments or severe limitations on discharges of hazardous materials. The atomic energy facilities have long been leaders in these applications. Since filters can be damaged by fire, many filter systems are protected by multiple banks, pre-filters, fixed and automatic water spray systems, sprinklers and the like. In radiation control areas where continuous ventilation is a part of the protective systems, fire dampers are not feasible and, as a result, a number of DOE systems have all of these protective systems on each filter bank.

The $5000 fire occured in 1980 in a plutonium recovery facility when a process overheated and activated an automatic filter deluge system. A manual backup system was also activated and the plant fire department used a booster line to complete extinguishment.

Several accidental losses have occurred in filter banks, a number resulting in no damage, but the largest, in a contaminated bank cost $6,254 in cleanup.

Trailers. Several thousand trailers are in use in DOE facilities. In addition to traditional uses, many are grouped into clusters and converted to offices and light laboratories. Sprinkler protection is provided on the same basis as other buildings. Even portable trailers are sprinklered, with hose connections to available water supplies.

A number of trailers have been destroyed by fire, but none that were sprinklered. The largest known fire in a trailer occurred in 1979 in a unit used for clothes sorting at a contaminated clothing laundry facility. An electric heater ignited a pile of clothes and one head on the preaction sprinkler system activated and extinguished the fire by the time the plant fire department arrived. (This incident is included in the laundry occupancy group).

High Explosives. Many high explosives operations are included in the Department's weapons activities. Sprinkler protection is universal, including the provision of a small deluge systems on individual operations.

The two fires in this summary include a "no-loss" fire in which scrap plywood barrier panels outside a test chamber were ignited by shot fragments when the chamber was opened. One head on the wet pipe system controlled the fire. The second involved the ignition of a barrel of scrap nitro-cellulose in which four old-style heads on a wet system extinguished the fire for a loss of $250.

A

Sprinkler Fires by Occupancy
(Including Paducah Fire & Two Failures)

Occupancy	No.	%	$Total Loss	%	$Mean Loss	Min. Loss	Max. Loss	1-2* Spri[nklers] No.
Laboratory	23	19.8	86,462	2.0	3,759	0	43,400	22
Warehouse	9	7.8	80,483	1.8	8,943	50	38,000	8
Plating Shop	8	6.9	176,039	4.0	22,005	323	91,500	4 (1 unknown
Unknown	7	6.0	9,074	0.2	1,296	0	6,000	6
GDP	8	6.9	3,176,584	71.9	397,073	0	2,900,000	0 (2 unknown
Office	5	4.3	10,122	0.2	2,024	0	7,095	4
Shop	7	6.0	3,750	0.1	536	0	1,400	5
Paper Shred.	5	4.3	0	0	0	0	0	5
Manufacturing	6	5.2	11,933	0.3	1,989	5	6,730	4 (1 unknown
Cooling Tower	6	5.2	38,445	0.9	6,408	0	15,300	(DEL)
Hot Cell	3	2.6	197,000	4.5	65,667	21,000	155,000	(DEL)
Mech. Equip.	3	2.6	3,510	0.1	1,170	10	2,000	1
Elect. Equip.	5	4.3	96,925	2.2	19,385	25	50,000	5
Laundry	3	2.6	4,550	0.1	1,517	300	3,500	3
Garage	3	2.6	243,502	5.5	81,167	0	243,000	2
Glovebox	2	1.7	300	0	150	0	300	1
Filter Bank	2	1.7	5,300	0.1	2,690	300	5,000	2
Computer	2	1.7	9,574	0.2	4,787	574	9,000	2
Transformer	1	0.9	244,800	5.5	--	--	--	(DEL) Failed
H. E. Process	2	1.7	250	0	125	0	250	1
Coal Conveyor	1	0.9	350	0	--	--	--	1
Change House	1	0.9	0	0	--	--	--	1
Accelerator	1	0.9	7,000	0.2	--	--	--	1
Dust Collect.	1	0.9	12,000	0.3	--	--	--	1 Failed
Dormitory	1	0.9	1,950	0	--	--	--	1
Foundry	1	0.9	1,300	0	--	--	--	1
TOTAL	116	100.0	4,420.803		38,110	0	2,900,000	81

*Overall 75 percent of the fires were controlled or extinguished by 1-2 sprinklers. (Th[ese] totals include deluge systems.)

Sprinkler Fires by Occupancy
(Excluding Paducah & Two Failures)

Occupancy	No.	%	$Total Loss	%	$Mean Loss	Min. Loss	Max Loss	1-2* Sprinklers No.	%
Laboratory	23	20.4	86,462	6.8	3,759	0	43,400	22	95.6
Warehouse	9	8.0	80,483	6.4	8,943	50	38,000	8	88.9
GDP	7	6.2	276,584	21.9		0		0 (2 unknown)	0
Plating Shop	8	7.1	176,039	13.9	22,005	323	91,500	(1 unknown)	50.0
Unknown	7	6.2	9,074	0.7	1,296	0	6,000	6	85.7
Shop	7	6.2	3,750	0.3	536	0	1,400	5	71.4
Manufacturing	6	5.3	11,933	0.9	1,989	5	6,730	4 (1 unknown)	80.0
Cooling Tower	6	5.3	38,445	3.0	6,408	0	15,300	(DEL)	--
Office	5	4.4	10,122	0.8	2,024	0	7,095	4	80.0
Paper Shred.	5	4.4	0	0	0*	0	0	5	100.0
Hot Cell	3	2.7	197,000	15.6	65,667	21,000	155,000	(DEL)	--
Mech. Equip.	3	2.7	3,510	0.3	1,170	10	2,000	1	33.3
Elect. Equip.	5	4.4	96,925	7.7	19,385	25	50,000	5	100.0
Laundry	3	2.7	4,550	0.4	1,517	300	3,500	3	100.0
Garage	3	2.7	243,502	19.3	81,167	0	243,000	2	66.7
Glovebox	2	1.8	300	0	150	0	300	1	50.0
Filter bank	2	1.8	5,300	0.4	2,650	300	5,000	2	100.0
Computer	2	1.8	9,574	0.8	4,787	574	9,000	2	100.0
H.E. Process	2	1.8	250	0	125	0	250	1	50.0
Coal Conveyor	1	0.9	350	0	--	--	--	1	100.0
Change House	1	0.9	0	0	--	--	--	1	100.0
Accelerator	1	0.9	7,000	0.6	--	--	--	1	100.0
Dormitory	1	0.9	1,950	0.2	--	--	--	1	100.0
Foundry	1	0.9	1,300	0.1	--	--	--	1	100.0
Total	113	100.0	1,263,003	100.0	11,177	0	243,000	80	70.8*

*Includes deluge and unknown. Overall, 75 percent of all fires were controlled or extinguished by 1 or 2 heads.

A9 Sprinklered Losses vs. Total Fire Loss

Chart A9 shows the total reported fire losses for each year since 1952 and the annual losses in sprinkler fires.

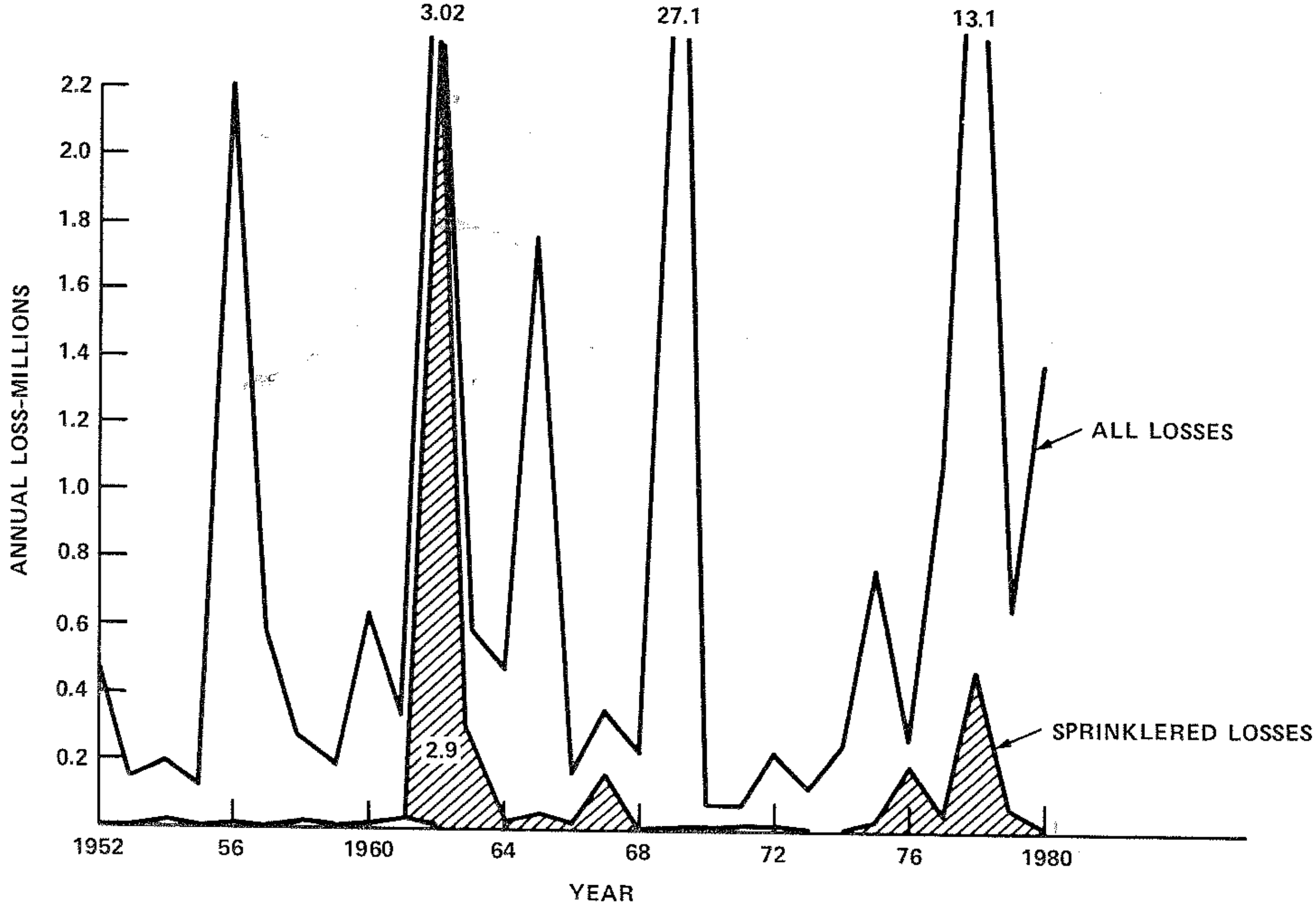
The cumulative reported fires since 1952 total $56.7 million as against $4.4 mi for the sprinkler fire portion of the total. Using the facility values for eac year, the comparable loss ratios were 0.96 and 0.07¢/$100 respectively ($96 and $7 per million).

Since DOE reporting includes forest, brush vehicle, oil drill rigs, and other n building occupancies to which sprinkler protection is not ameniable, the detail losses available since 1975 were reviewed and losses in which sprinklers would not have been a feasible protection system were deleted. For this period the total loss in buildings was $3.6 million and the sprinkler losses were $0.8 mil Using the values for this period, the respective loss ratios were 0.14 and 0.03¢/$100 or $14 and $3 per million of value.

The 5 to 1 superiority of sprinklers is understated in 2 ways. The sprinkler data includes 37 fires that were not reportable under the DOE loss reporting criteria (although the total loss from these fires was only $5,349). More impo it is safe to assume that the facilities with the largest fire loss potentials the ones that are sprinklered, therefore the loss, if those facilities had no been sprinklered would have far exceeded the 5 to 1 ratio.

Since the only true comparison of the loss reduction value of sprinklers would come from comparing identical fire scenarios in identical occupancies with and without sprinklers, it is obvious that the exact value cannot be determined.

Regardless of the above, the value of sprinklers to DOE has been proven conclu sively. The Paducah fires (see Section A1 and Appendix D) resulted in an $18 million project to sprinkler the gaseous diffusion plants and the second f if the sprinklers had not been installed, would have resulted in a loss exceed $100 million. Since the total area of all DOE facilities is a little over 100 million sq.ft., every square foot of space in DOE could have been sprinkle with just the savings from the 1962 fire alone. When programmatic and public impacts are added, it is clear that the automatic sprinkler system has more th proved its worth in DOE.



SPRINKLERED FIRE LOSS VS. TOTAL FIRE LOSS

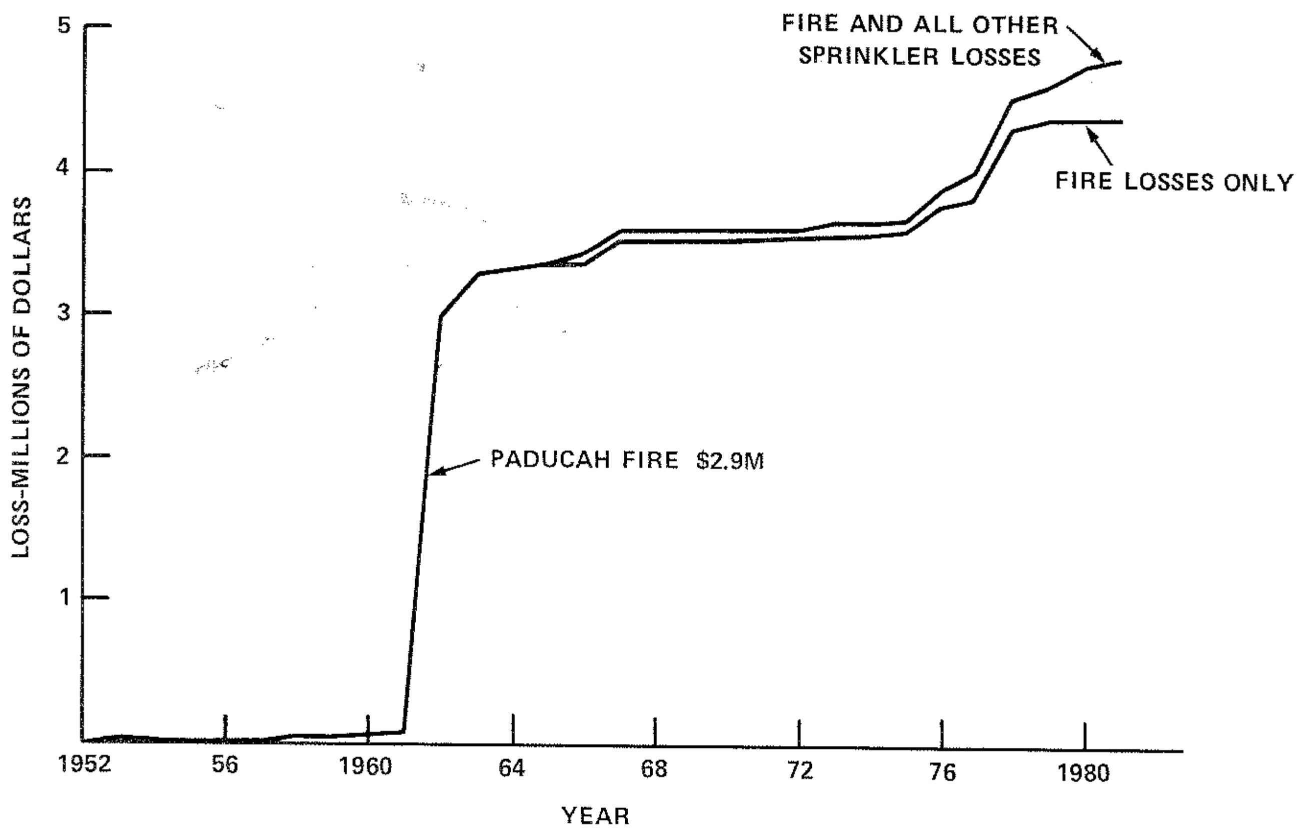
A10 Effect of Large Losses

Chart A10 illustrates the effect of the large, but rare, loss in graphic form. In this case the single loss in 1962 clearly overshadows all other losses combined. With the exception of a moderate jump due to two losses in 1978, the year-to-year trend appears almost flat when drawn on any reasonable scale.

Utilizing this type of "trend report" can be very misleading. If the 1962 Paducah fire had occurred at the start of the period covered, the subsequent straight-line curve could give the false impression that everything had been controlled and there was no longer any need for concern about potentialities. Conversely, a sudden jump at the end of the period would look like everything had deteriorated at one stroke and inspire a search for accident "scapegoats."

In reality, the large loss may be an integral part of the "existing" system of fire protection and simple trend plots, such as this, cannot inform us as to what should be expected on a year-to-year basis. Indeed, we cannot even be sure that the maximum loss has yet occurred, or how often it may recur. A fire protection engineering analysis can yield a good estimate of what the maximum loss might be, but more sophisticated techniques must be used to determine the frequency.

The most important need is for a system to determine whether or not the rare large loss is an isolated incident or part of the system. If the large loss is truly a rare and isolated event, resulting from special conditions, then the typical accident recommendations can, indeed, prevent that accident from recurring. If the accident, however, is a natural consequence of the accepted fire protection program, and that consequence is unwanted, then the only "fix" is to change the systen. It is for this reason that the technique demonstrated in Section A11 was developed.



CUMULATIVE LOSSES IN SPRINKLERED FACILITIES
AEC/ERDA/DOE
1952-1981

All Extreme Value Projections

The extreme value projection technique has proven to be a useful tool in DO safety analysis work and is taught as a part of the Accident/Incident Inves gation Seminars and a newly-developed Risk Management Workshop.[1]

The plot of maximum annual fires indicates a return period of 7 years betwe losses of the order of $100,000 and about 30 years between sprinklered loss of $1 million or greater.

Utilizing the extreme value probability graph paper, the points are seen to lie on a straight line, indicating that the losses are occurring within a system and that to change the frequency of large losses would require chang the system, not just the individual "quick-fixes" dictated by a particular loss. Within this system, a point well off the curve would indicate that there are special conditions applicable to that point.

The Paducah fire illustrates the above. It is a "flyer" on the fire plot, indicating that it had special features not within the usual sprinkler fire "system" of AEC/ERDA/DOE. Indeed, this was the case as the incident was initiated by a chemical reaction deflagration and the bulk of the damage occurred before the sprinklers operated (and the sudden massive steam-heat release was the principal reason so many sprinklers opened).

The "dog-leg" phenomenum is common on extreme value projections of losses. The line in the $1,000-10,000 range is much steeper than for the larger losses (indicating a much more frequent return period). For sprinkler loss this can partly be explained by the high value of DOE facilities. As of 19 the mean value of DOE's total building area was about $545 per square foot. Although DOE occupancies and values are so varied that an overall mean has little likelihood of applying to a specific facility, it is obvious that a number of fires may cause considerable damage before a sprinkler system operates, even though one head may extinguish the fire. For this, and simi reasons, it is not generally good practice to extend an extreme value proje beyond the next order-of-magnitude.

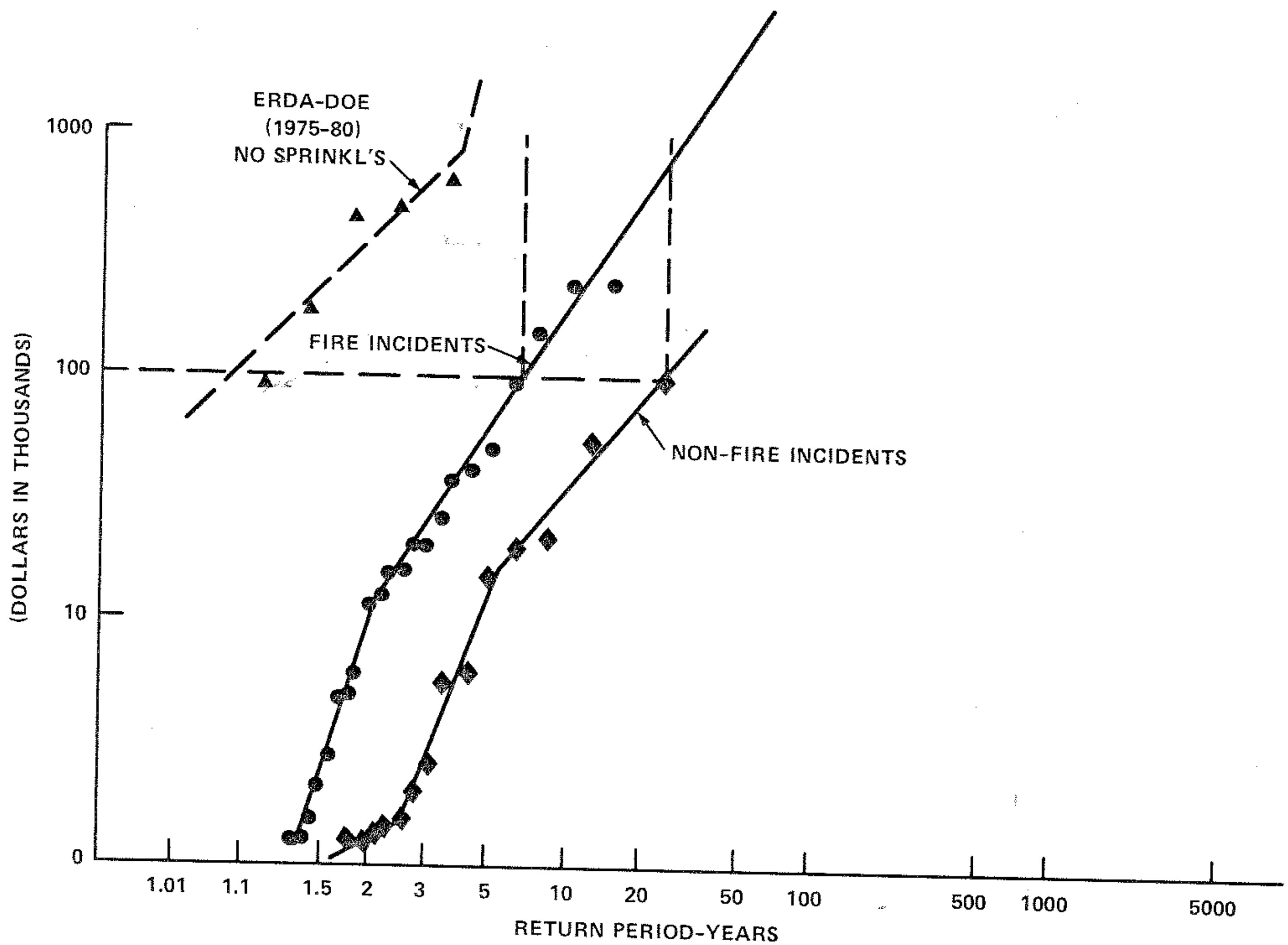
For comparison, a projection of all extreme value fires in the ERDA/DOE per (1975-1980) is included. None of the maximum fires in these years were spr fires. The points form less of a straight-line projection because they inc such widely-differing fires as a forest fire and a major petroleum drill ri fire.

For non-sprinklered fires, the $100,000 fire loss appears to be at least an annual occurrence and the $1 million fire has a 4-5 year return period, or about 5-6 times as frequent as the sprinkler fires.

The "dog-leg" on the all-fires plot is due to the drill rig fire that resul in a $12,000,000 loss at the Strategic Petroleum Reserve in 1979. Since th were no losses in the $1-10 million range, it is not clear whether or not t projection should be a straight line, in which case the oil rig fire is a " not conforming to the "system." Clearly an oil rig is a distinct type of h and loss modes and protection systems will differ sharply from other "syste Thus, such fires should be considered within a petroleum industry or drilli rig operation system.

The non-fire incidents involving sprinklers have also been plotted. In this case the $100,000 loss would appear to occur about once in 25 years, while a $1 million loss appears to be a once in 200 years event. However, since this is more than an order-of-magnitude projection, it has less validity as a prediction. Since the actual loss record for the 33 years since 1947 shows no loss exceeding $100,000, the probability of a major loss is undoubtedly small.

[†] A complete description is the subject of National Bureau Standards' Applied Mathematics Series-33 (1957) by Emil J. Gumbel. A short explanation, with examples is in the DOE System Safety Development Center guide SSDC-11, Risk Management Guide, June 1977.



EXTREME VALUE PROJECTIONS

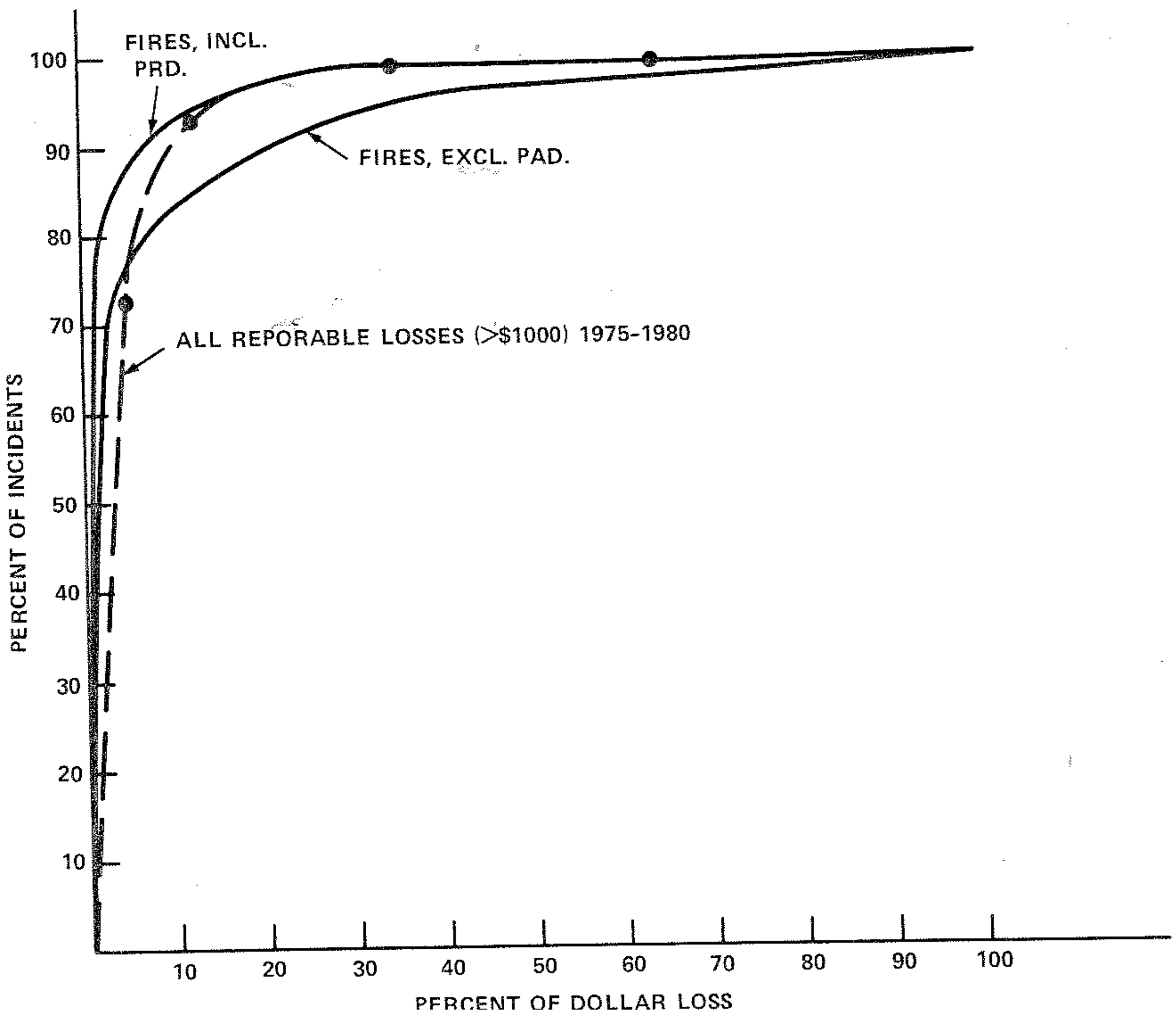
A12 Cumulative Percentages, Losses vs. Incidents

The data plotted in Figure A12 illustrates the effect of the rare, large losses in another fashion. This shows the cumulative percent of incidents by the cumulative percent of losses.

For the sprinkler fires in this summary, 90 percent of the total incidents add up to only 7 percent of the total loss. Even if the one fire that accounted for over half of the total is excluded, the 90 percent of the losses still account for only 20 percent of the dollar total. In both examples, 75 percent of the incidents account for less than 5 percent of the loss.

Note that over 10 percent of the incidents resulted in 0 percent of the loss, the effect of the number of "no-loss" sprinkler fires included in the system. By contrast, a curve is included for all losses of all types reported to DOE Headquarters for the period 1975-1980. Since the reporting level omits all losses below $1000, it might be expected that the majority of the losses would persent a clearer picture of the total loss that might be expected. However the plotted experience shows that the curves are nearly identical, even though there are now 633 incidents and none lower than $1000.

This section again demonstrates the need for, and value of, the extreme value projection technique illustrated in Section A11. Any open system of loss reporting and analysis (any system in which future reports will be added to the data base) has obviously not collected 100 percent of the incidents. If one or more of the large losses have not yet occurred, than any manipulation of accumulated data that does not utilize a predictive technique will result in a very misleading view of the true system.


FIRES, INCL. PRD.
FIRES, EXCL. PAD.
ALL REPORABLE LOSSES (>$1000) 1975-1980
PERCENT OF INCIDENTS
100
90
80
70
60
50
40
30
20
10
PERCENT OF DOLLAR LOSS

A13 No-Loss Fires

In view of the large median losses reported in other summaries, mostly insurance company statistics, and considering the high value of many DOE facilities, the number of relatively insignificant fires included in this study may seem surprising. There are 29 fires included in which the total loss was under $100.

The 20 incidents reporting "no loss" include 5 paper shredder fires over a period of about 4 years. In each case, two heads on a wet pipe system extinguished the fire.

Three incidents involved waste bags or garbage pails, one of which was in a radiation-environment glovebox. In two cases, one wet-system head extinguished the fire. In the glovebox fire, a single multi-cycle head controlled the fire while an operator used an auxiliary extinguishing material.

Two fires involved change rooms in which some clothing was damaged but no government loss to facilities or equipment resulted. Both cases were extinguished by two heads each, one involving a wet system and one involving a dry system.

Only two cases involved more than two heads. One was a lube oil spill ignition in a diffusion plant, controlled by three heads. The building volume is vast and there were no other combustibles in the area to be ignited. The other case was the rubberized horsehair incident, involving 20 heads, noted in Appendix C.

Obviously, a minimal cost can be assigned to any sprinkler operation. If nothing else, the cost of replacement heads will be a few dollars, and an accounting cost can be assigned to the replacement labor. A number of the statistical tables in this study were reworked, using an arbitrary $50 as a minimum charge per incident. The overall change in mean losses was so small that no practical benefit could be achieved, since the costs assigned to major losses are often arbitrary to the extent that a few percent change in a single large loss would overshadow the total effect of any minimal adjustments.

The use of a "no-loss" figure is realistic in many cases. Since DOE facilities have in-plant fire departments, and large maintenance staffs, there is no added real cost if they replace a sprinkler head. Also, many plants have so many spare heads on hand that they have never actually had to purchase replacement heads.

At the other extreme, the total loss to DOE is probably overstated. Losses are required to be reported on the replacement value of equipment or facilities and a number of fires have been assigned sizable loss figures when, in fact, no replacement or repair was ever done.

In view of the above, all "no-loss" reports were included as submitted.

A14 Sprinkler-Fire Fatalities

Throughout the history of the Manhattan Engineering District, Atomic Energy Commission, Energy Research and Development Administration, and now the Department of Energy, there have been no fatalities due to fire in a sprinklere(facility.

The 1976 summary of fire and property loss experience stated:

> "Throughout the history of MED-AEC-ERDA operations, beginning in 1943, thirteen people have died of burns. Three incidents killed two people each and the remaining died in seven single fatality incidents. All of the incidents occurred as a result of explosions or flash fires instantaneously involving the employee. There have been no burn fatalities in the last 10 years, and there is no record of any fatality occurring in a sprinkler protected facility.
>
> Two firemen and one medical technician have been killed in the same period, all as the result of vehicle accidents."

Since then, with the addition of oil field operations to DOE, there have been seven fire fatalities in four oil field operations; two drill rig blowoutfires, one field ignition of vapor-saturated clothing, and one of a barge hitting an underwater gas pipeline.

The only fatality in which a sprinkler system was involved occurred on February 1977, when a plant electrician at one of the gaseous diffusion plants was replac motor breaker current transformers in a building electrical equipment room. He erroneously entered an energized cubicle and shorted the energized studs, receivi third-degree burns from which he died 8 hours later. Three other employees received minor injuries. Two heads on the ordinary hazard, wet pipe sprinkler system controlled the resulting fire while employees and plant fire department completed extinguishment with hose streams and a total of one 15 lb. CO_2, one 20 lb. dry chemical and six 50 lb. CO_2 extinguishers. The fatality was due to the initial electrical contact and the sprinkler operation did not affect that. However, the prompt operation might have helped prevent additional injuries to the other workers in the area. Property damage was listed as $55,430 in the investigation report and $50,000 on the sprinkler summary data sheet.

A15 Effect of Height of Heads

One of the data elements collected was the height of the sprinklers above the floor in fire incidents. An arbitrary dividing line of 10 feet was selected with the intent of separating fires occurring in high-bay areas from the usual ceiling heights common to offices, light laboratories, residential and computer occupancies.

For older fire reports, this datum was not generally available and most of the data collected is from the supplementary reports submitted in response to the questionnaire. Thus, about two-thirds of the total fires had the height of the sprinklers identified. Data is summarized in the accompanying Table and Chart A15.

It has been well demonstrated in many fire tests that the intensity of a fire varies as an exponential of the height of the burning material. Thus, if a large number of similar cases could be collected, it would be expected that both the dollar loss and the number of sprinklers operating would increase by a factor greater than the linear. The collected data, while sparse, and utilizing only two height classifications, seems to offer dramatic confirmation of this point.

Both the mean and the maximum losses, even excluding the most dramatic high-sprinkler fire, are greater for the high-head fires by more than an order of magnitude. The mean number of heads operating per fire was a factor of seven greater for the higher heads.

As would be expected the lower heads were more successful in extinguishing the fires without other assistance (45 percent vs. 28 percent).

One failure did occur in the lower range. This was the cold weather valve controlled head that was shut off at the time of the fire. (The deluge system failure in which the spray nozzles surrounded the transformer could also be considered as "less than 10 feet" above the fire.)

On a cumulative basis, all of the low-head fires were extinguished by seven heads or less. Even though the plotted data points are too few to be significant, it is interesting that, even for the high range of sprinklers, 75 percent of the fires involved seven heads or less.

In both categories, wet pipe systems were the majority (78 percent and 67 percent). Due to the few dry (or preaction) system fires (see Section A3) it is not possible to draw conclusions for wet vs. dry system performance. Ideally, of course, a suitable number of cases should be able to demonstrate a difference between occupancy groups, and type of system, for each of a number of height ranges. Unless a group of major insurers could expand their collected data over a long period of time, it is doubtful if such distinctions could be conclusively demonstrated.

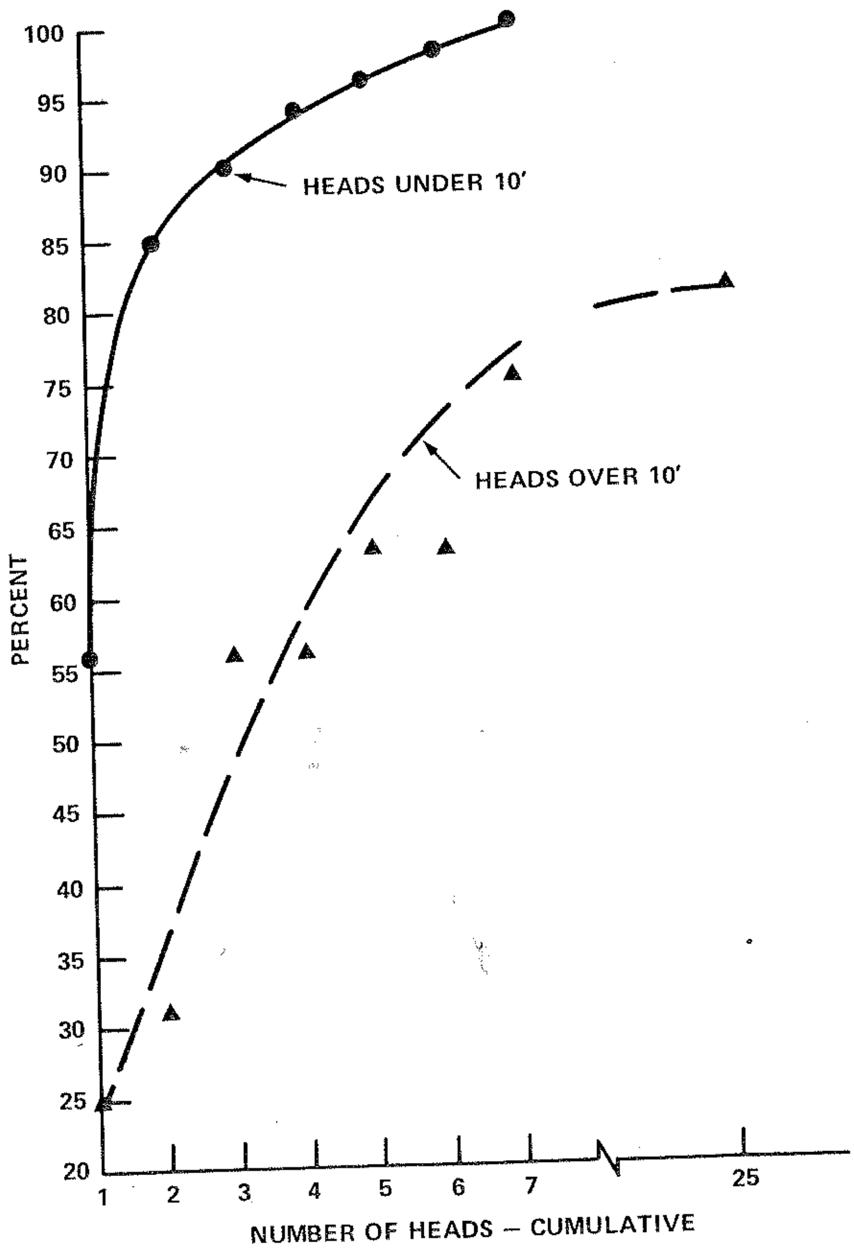
An important factor missing from this study (and from nearly all fire reports) is the value at risk, either as a calculation of the dollars per square foot at risk in the fire area, or as the estimated probable loss in the absence of sprinkler operation. The author has some evidence that, in DOE, the fire loading in BTUs per square foot is higher in low-head areas while the load in dollars per square foot is lower. This would increase the discrepancy mean losses in high-head areas, but again, not enough data is available to usable.

For the reasons discussed above, the number of negligible losses would be expected to be greater in the low-head cases, but the data does not show t (in fact the high-head cases are greater, by 22 percent to 18 percent), bu number of incidents is too few to attach any significance to the figures.

A1

EFFECT OF HEAD HEIGHT

Item	Heads Under 10 ft.	Heads Over 10 ft.
Number reported	55	18
Total Loss	$197,829	3,557,197
Mean Loss (including Paducah)	3,597	197,622
Mean Loss (excluding Paducah)	3,597	38,659
Total Extinguished (%)	25 (45%)	5 (28%)
Total controlled (%)	28 (51%)	12 (67%)
Total unspecified (%)	1 (2%)	1 (5%)
Total failures (%)	1 (2%)	0 (0%)
Number of heads opened and Cumulative %		
1	27 (56%)	4 (25%)
2	14 (85%)	1 (32%)
3	2 (90%)	4 (56%)
4	2 (94%)	0 (56%)
5	1 (96%)	1 (63%)
6	1 (98%)	0 (63%)
7	1 (100%)	2 (75%)
25	0	1 (81%)
149	0	1 (88%)
2431	0	1 (94%)
Unknown	0	1 (100%)
Deluge	7 (-)	2 (-)
Total heads operating	87	211
Mean heads per fire	1.6	11.7
Type of System		
Wet	37	14
Dry	4	0
Deluge	7	2
Preaction	2	0
Antifreeze	1	0
Multicycle	0	2
Unspecified	4	0
Maximum Loss	$43,400	$2,900,000 ($243,000 excl. pad.)
No of "No-Loss" Incidents	10 (18%)	4 (22%)



EFFECT OF HEAD HEIGHT
CUMULATIVE PERFORMANCE

A16 Standard vs. Old Style Heads

An attempt was made to determine the effect of standard, or spray-type heads compared to the old style or pre-1954 heads. Unfortunately, the number of incidents in which the style of head was specifically noted was limited to only 11 of the old-style heads and 56 of the standard. The data was reduced to Table A16 and Chart A16.

Although there was only one incident in which more than four old-style heads operated and the number of other incidents is too sparse to have much statistical validity, the available data does seem to confirm some presumptions, namely:

1. The spray heads seem to be a little more effective in reducing the number of sprinklers likely to operate in a fire.

2. The mean loss in small fires is likely to be less with spray heads.

3. The difference between old-style, and new, sprinkler systems is likely to be very small.

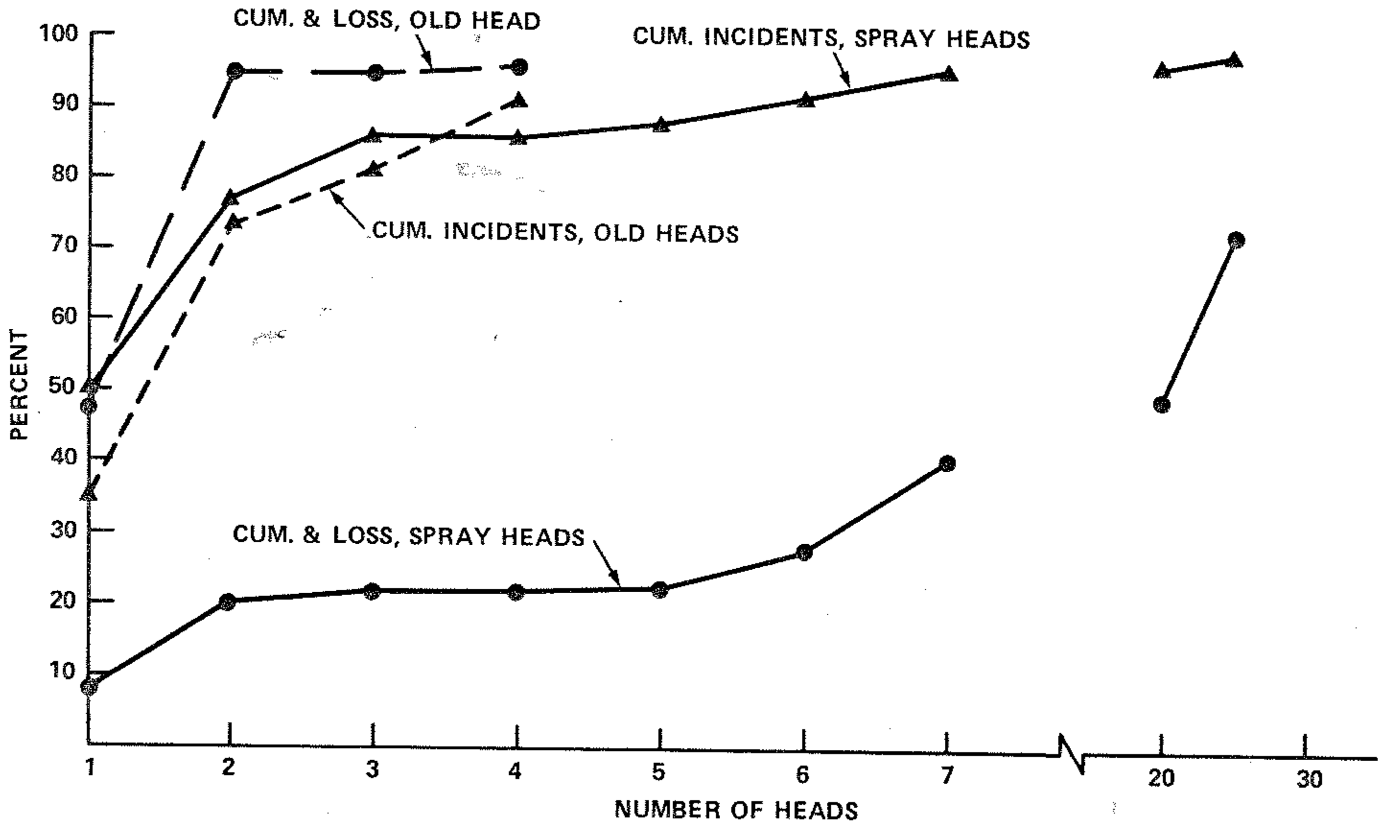
The limited DOE experience would appear to confirm the NFPA sprinkler committee's reasoning behind the 1954 and subsequent codes. As explained by Thompson,[1] the new spray head was so much more effective (as is apparent in the one-head operations), that the spacing was changed from a 100 sq.ft. per head limit for ordinary hazard occupancies to a 130 sq.ft. per head limit. Thus the single-head operation will show the effectiveness of the spray head, while multiple heads would have the individual advantage masked by the effect of greater fire area involved (at maximum spacing the new system will protect 30 percent more area than the old, or nearly 100 sq.ft. for 3 heads). Since DOE's mean dollar density is about $500 per sq.ft., a number of multiple-head fires might even show unfavorable performance for old systems as compared to new. Even if the data were available, this conclusion would be invalid since it could not be shown how many extra heads might have been opened if they had been old-style instead of new. Even if the heads were equally effective, a 20-head fire with new heads, (2600 sq.ft.), should probably be compared to a 26-head fire (2600 sq.ft.) with old heads.

[1]Fire Behavior and Sprinklers by Norman J. Thompson, NFPA, 1964

A16

STANDARD VS OLD STYLE HEADS

No of Heads	Standard (Spray)			Old (Pre 1954)		
	Incidents	$ Mean Loss	$ Max Loss	Incidents	$ Mean Loss	$ Max Loss
1	28	$2,536	23,000	4	4,463	12,000
2	15	7,088	38,000	4	4,627	13,091
3	5	2,650	12,000	1	0	0
4	0	--	--	1	247	247
5	2	3,698	7,095	--	--	--
6	1	43,400	43,400	--	--	--
7	2	58,992	91,500	1	1,503	1,503
20	1	76,030	76,030			
25	1	200,104	200,104			
144	1	243,000	243,000			
TOTAL	56	15,509	243,000	11	3,464	13,091



STANDARD (SPRAY) VS. OLD (PRE-1954) HEADS

A17. Frequency-Severity Plot

Since previous sections have demonstrated the distorting influence of the large-but-rare loss on the mean losses, another tool is necessary to determine how losses, not yet experienced, can be included in a usable figure for loss-per-incident, or losses-per-year planning or analysis purposes.

Section A11 has demonstrated a system, Extreme Value Projections, for estimating the frequency of very large losses, and determining whether or not they are to be an expected part of a given protection system. This section demonstrates the additional information that can be obtained through the use of frequency-severity plots.

Utilizing the technique demonstrated in the Risk Management Guide, SSDC-11 (See Section A11 reference) all of the incidents in this study were grouped according to cost and plotted on a log-normal plot, as shown on Plot A17-1. This is analagous to the Extreme Value Plot except that all incidents are included. Two possible plots "fit" the data, as shown by the straight and dashed lines. Both are discussed below.

Accepting the straight line as the best fit to the data points, the probabil of a million-dollar loss is about 2.5 percent. Since there were 117 losses the data, this would correspond to about three losses of a $million or more, with slightly over four sprinkler losses each year, an expectancy of about one $million loss every 9 years. The Extreme Value Projection derived a frequency of about 30 years, which corresponded more closely to actual experience.

An alternate, dashed line is plotted to the same points, considering that previous sections have noted that the number of low-loss incidents may be somewhat greater than reported, and the Extreme Value Plot has already demonstrated that the single loss exceeding $1 million was an anomaly. Thu the middle ranges probably represent a truer picture. Indeed, replotting the line on these points yields exactly such a curve, with the large loss actually experienced occurring sooner than would be predicted and the lowes range somewhat less frequently.

Transferring these curves to a log-log distribution yields plot A17-2. Now, by integrating the frequency-severity curve, the mean value of an incident is determined and the point at which the slope is unity is the range of maximum losses. For the most probable curve (the dotted line) an integration-by-approximation (an adequate method for the limited data) yields an expected loss of $54,700. This compares to the arithmetic mean of about $38,000 for the 117 incidents. Thus, for DOE, the "most probable" loss to assign to a sprinkler fire would be about $55,000. This method allows the large-but-rare losses to be incorporated.

Similarly, the integration yields the largest component of the combined loss in the range of $100,000 - 1,000,000. In fact more than half ($30,000) of the total approximate integration of $54,700 is from the expected losses in this range. This is the range at which the slope changes from less than one to more than one, conforming to the theory and to DOE experience.

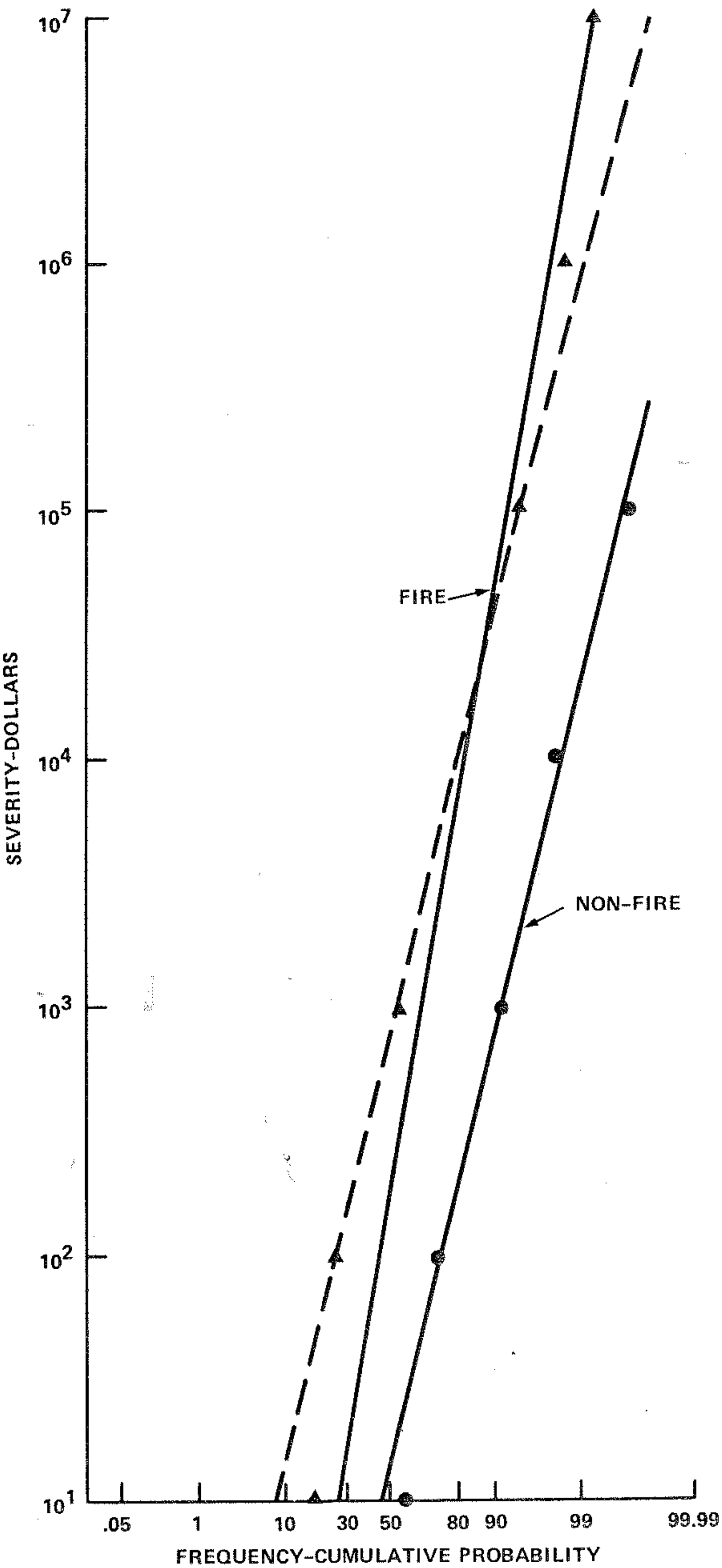
The frequency-severity plot is also useful when a "line of balance" (a uniform slope of one) is plotted from upper left to lower right corners. The ideal loss system, in theory, would lie along this line. That is, the single $ million loss would be no more likely to occur than ten losses of $100,000 or 1000 losses of $1,000. In effect there would be as much effort devoted to alleviating large losses, as to small losses. In actuality, all systems are far more tolerant of frequent small losses than of rare, large losses, even though the totals may be the same. AEC/DOE emphasis has been on the prevention of large losses and frequency-severity plots of other systems, particularly radiation exposure, demonstrate the phenomenum. For fire, the $1 million loss potential is the point at which DOE makes automatic protection systems mandatory. While this may not be justified by a pure theory of loss-prevention effort, it is certainly justified when public impact is considered. The public impression of the three fatalities in AEC's 1961 SL-1 reactor accident (the only radiation deaths in reactor history) far exceeded the combined impact of the other 318 fatalities from all causes of AEC's 33-year history.

The plots also show the non-fire sprinkler experience. As would be expected the maximum potential and the mean loss are both more than an order-of-magnitude less than would be expected from fire losses. The integrated mean loss is about $1100 as compared to the arithmetic mean of less than $900. Again this is a better "average loss" to be expected from a sprinkler damage incident as an allowance for the rarer losses is included.

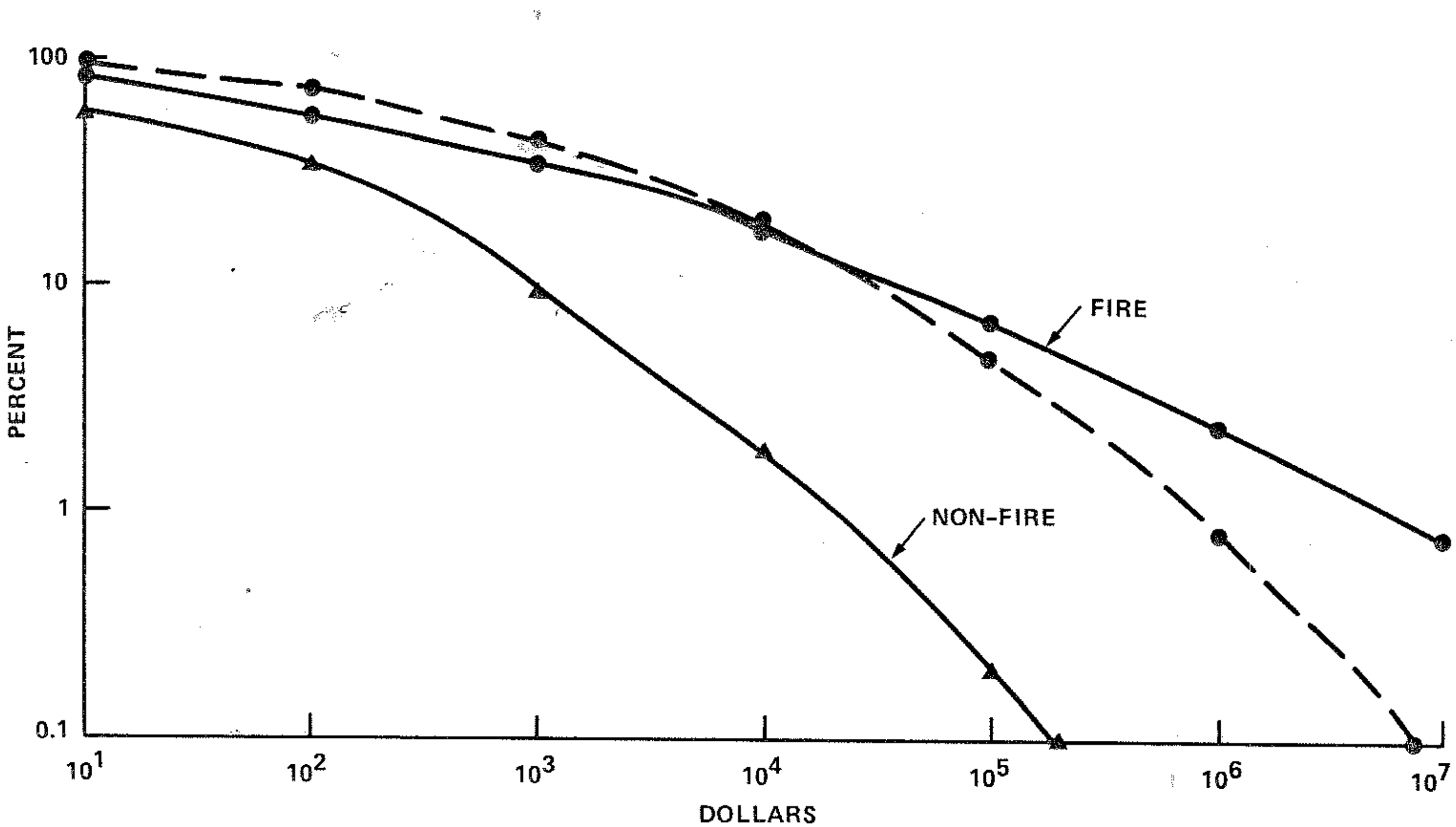
The range accounting for the largest portion of non-fire losses is the $10,000 to $100,000 range, which accounts for over half the total. Again, this is an order-of-magnitude less than the similar fire incident range.

The range $100,000 to $1 million, in which no accident has yet occured, accounts for about $150, or about 13 percent of the integrated mean loss figure.

From the frequency-severity plot A17-1, losses exceeding $100,000 would equal about 0.2 percent of the total. If the 470 losses had occurred equally over the 28 years of the study, this would translate to a loss exceeding $100,000 about once every 29 years. From the extreme value plot (A11) the expected return period is about 25 years. Thus the two systems are in close agreement. The fact that most of the incidents were reported for recent years adds an extra-value to the frequency-severity system since it applies to any frequency of reported incidents (assuming the system itself is not changing).



FREQUENCY-SEVERITY



FREQUENCY-SEVERITY

A18 Miscellaneous Sprinkler Data

The following section contains several items pertaining to DOE sprinkler systems that are applicable to the study. Data is also summarized for several categories in which the amount of information collected was not comprehensive enough to draw more than tentative conclusions.

High-Temperature Heads

Data on temperature rating of sprinkler heads was included in the questionnaire, with temperatures in excess of 212°F as the dividing line (212°F heads are routinely installed in many areas, such as computer rooms, where the justification is not high ambient temperatures but slower response time, supposedly reducing the chance of non-fire actuation).

Four fires involved high temperature heads. A single head extinguished lab fire for negligible loss (pipe insulation); a single head extinguish an office fire when an A/C unit overheated and ignited, for a $252 loss; two heads (picker trunk type) extinguished a grease fire in a duct in a food service area of a computer occupancy, for a loss of $574; and two heads controlled a fire in a contaminated laundry trailer when radiation monitoring equipment shorted and ignited clothing. This was the largest loss, $3500. The mean loss was $1082, with the range from $0 to $3500.

Fire Department Response

Only five fires occurred where on-site fire department, or well-trained brigade, response was not available. In every case, the fire was extinguished by the sprinklers alone. Three fires, the largest of which resulted in a $260 loss involved only one head. The remaining two fires each activated two heads. The mean loss was $693 and the largest loss was $1,705.

Waterflow Alarms

There was one incident in which the waterflow alarm was turned off. It did not affect the loss as personnel were present and called the fire department. Two heads controlled the fire, an overheated accelerator magnet, for a $7000 loss.

Closed Valves

There were no failures from closed valves.* All DOE fire protection valv must be capable of being locked and the majority are either locked or electrically supervised (electric supervision is preferred and a number are both locked and supervised). In addition, a majority of DOE sprinkl systems are inaccessible to the general public and the supervision from on-site fire protection engineers, full-time inspectors, and plant fire departments is more universal than in the general run of industrial occupancies.

*The "failure" in this report was an intentionally closed system.

Hydraulically Designed Systems

This alternative has found increasing acceptance in DOE facilities since at least 1958. A number of sites have developed their own computer-design systems and have applied hydraulic design to all systems installed for several years. Argonne National Laboratory has been especially innovative in this area.

The gaseous diffusion plants, with eleven major buildings of several million square feet each (66 sprinkler systems in the one building of the Paducah fire) were designed for a 0.15 gpm/ft. sq. density and one site has routinely designed systems for 100 head flows.

The survey collected data on fires involving hydraulically designed systems in two broad categories; over 0.2 and under 0.2 densities. There was only one fire involving the higher density; a $750 laundry fire in which only one head operated.

In the lower density range, there were six fires identified. In addition to the major Paducah fire, these were; a $450, three-head loss; the $200,104 loss involving 25 heads (see Appendix D); a $91,500 loss involving seven heads on a multicycle system; and two fires of negligible loss, one involving one head and a multicycle system and one unidentified.

Pipe Schedules

Despite the prevelance of hydraulic design, the majority of DOE sprinkler systems are "ordinary-hazard" pipe schedule systems. DOE fire protection criteria has long excluded "light-hazard" pipe schedule systems based on the fact that the occupancies for which they were most commonly proposed have frequently been those actually having the highest fire loadings, particularly computer and scientific offices.

Of all incidents, both fire and non-fire, only three involved "light hazard" systems, none of which was fire-related. The highest loss was $283 when an inspector's test valve froze.

Eight incidents involved "extra-hazard" systems. The largest extra-hazard loss was $14,000 and none of them involved fire.

Non-Sprinkler Systems

Sprinkler systems are by no means the only type of protection system installed. In the same 1966-1980 period in which there were 1,408 sprinkler systems retrofitted in DOE facilities, there were 556 halon systems, 38 CO_2 systems, 22 foam and 7 dry chemical automatic systems installed. All in addition to 49 new fire trucks and 20 other fire department vehicles. Actual fire experience has been lacking except for two recent Halon System fires. One, in a computer, extinguished the fire for a savings of at least $85,000, and possibly as $1 million.

Earthquake Bracing.

Many DOE sites are in recognized earthquake zones (California, Idaho, Tennessee, South Carolina, etc.) where NFPA 13 earthquake bracing requirements are applicable.

There have been three earthquakes resulting in reportable damage at DOE facilities, all in California. The only one in which sprinkler systems were affected was the January 24, 1980, earthquake near Livermore California, which affected the Lawrence Livermore National Laboratory ($3,016,000 damage) and the Sandia National Laboratory-Livermore ($400,000 damage). Regarding approximately 200 sprinkler systems at these sites, the following is quoted: (1)

The largest loss of the year, and the largest ever as the result of natural causes was the result of the 5.6 (Richter scale) earthquake in the Livermore, California, area on January 24, 1980. Damage to facilities and equipment at the Lawrence Livermore and Sandia (Livermore) National Laboratories totaled $3,416,008.

"Damage was principally due to: structural cracks; sheared equipment supports; overturned furniture; equipment and bookcases; dislodged ceiling tiles; and dismounted trailers."

"In regards to fire protection systems, the SAN summary noted:"

> "An earthquake of approximately 5.6 on the Richter scale caused in excess of $3 million damage at LLNL but all major fire protection systems and the site water supply system remained in service. Four sprinkler heads were damaged and about a dozen small fittings leaked. One of seven non-standard PVC sprinkler systems installed in trailers was severely enough damaged to be shut down and eventually replaced with a standard pipe schedule system."

> "Considering that the two sites affected contain about 290 buildings (plus numerous trailers) totalling about 3.4 million square feet of floor space, and the $3.4 million loss was about 0.7% of the site value, the damage could hardly be called extreme. However, the accident generated press interest out of all proportion to the loss; principally from a "radiation leak" and damage to a plutonium facility. The damage to the facility was principally to the mechanical equipment wing, which did not require the strength of the lab/ventilation loft wing and the "leak" was tritiated water at about half the permissible drinking water level - and all confined to a dike at that. As pointed out so often before, protection of facilities from the "public impact" standpoint may require far more effort than would be justified solely from a real hazard potential."

Office-Type Occupancies

The November 1972 Fire Journal cited New York City high-rise fire experience of 41 fires over a 3 1/2 year period. Of these, 34 or 83% involved one sprinkler; five more, or 95% cumulative, involved 2 sprinklers; one more, or 97.5% involved three sprinklers; and the last involved four sprinklers.

An approximately similar DOE experience would be the fires in office, cooridors, janitors closets, computer rooms, and canteens. There were 12 of these with a mean loss of $1,933 each. One did not list the number of heads involved. Of the remaining, 82% involved one head, a cumulative 91% involved two heads or less, and one involved five heads.

All were wet pipe systems and all, except one unidentified, were ordinary hazard pipe schedule systems.

The New York City experience noted that "85% did not require hose." In the DOE experience, five were identified as being completely extinguished by the sprinklers and five as controlled (meaning either hose or portable extinguishers were applied in addition to the sprinklers.)

Mean loss for "extinguished" was $2,139 and, for "controlled," $2439.

Mercury Check Valves

An October 23, 1979, memo summarized results of a survey of mercury check valves, used in zoning pneumatic detection systems, following a manufacturers notification of a possible problem (primarily scale formation) that could lead to possible failures. There were 202 such checks in DOE, of which a few showed signs of scaling, although none failed in test. Of these, 96 were replaced (one site noted a number had been installed in 1949-50, but all had been replaced in 1965).

Effect of Inflation

All costs of damage are for the year in which the incident occurred. Since the data is cumulative from 1952, and inflation has been high in recent years, the same loss to the same materials or structures, when separated by 20 years, will show an apparent difference in severity that is misleading.

In DOE, losses are reported using current replacement values, whether or not any replacement was actually made, and facilities and equipment values are updated annually, using Factory Mutual or Engineering News Record indexes. Thus, data presented as a loss ratio, or cumulative ratio is self-correcting for inflation.

Several different indexes were applied to individual losses in an attempt to provide a revised format for the presentation of the minimum, mean, and maximum losses. Since each index is different, this yielded slightly different results for each case. More importantly, the indexes are limited to broad industry-wide categories, while each loss affected one type of property, one category of equipment, etc. Attempts to adjust each loss according to building, industry, or equipment type was fruitless as most losses are not broken down into each category.

The November 1, 1981, Fire Journal, in the summary of large loss fires, used the Producer Price Index[2] for comparing prior years data. In this index, 1967 is 100 and January-May 1980 is 260. Utilizing this system, the sum of losses is the same as reported here if 1975 is chosen as an index of 1. That is, increasing losses after 1975 and decreasing those before 1975 by the revised index (if 1971 is 100, 1980 is 145) yields the same totals as the sum of the losses at the value of the year in which they occurred. In that sense, all losses can be considered to have occurred in 1975. In 1980 dollars, the total losses would be about 50% greater than reported here.

Other Extinguishing Agents

In 47 of the "controlled" sprinkler fires, the other agent was listed as "hose" on 29 occasions, and "extinguishers" on 12 occasions. Both extinguisher and hose were used five times, and hi-expansion foam once.

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[1]DOE/EP-0053/2 Summary of Property Damage Control Programs of The United States Department of Energy CY 1980.

[2]The Statistical Abstract of The United States, 1980 Government Printing Office, page 481, Table 800.

PART B NON-FIRE EXPERIENCE

B1. Non-Fire Sprinkler Incidents.

There were 470 incidents involving sprinkler systems other than fire actuations. A significant number resulted in no loss and, in the majority of cases, the only damage suffered was that suffered by the sprinkler system.

It is clear from the minor nature of many of the incidents, that a definition of the nature of an incident is critical to the number of incidents accumulated. For instance, in addition to the traditional "sprinkler leakage" losses, where accidental operation or rupture of a sprinkler system damages the building and its contents, there were many cases that would not normally be reported. These included false actuation of deluge systems in cooling towers where little more than resetting of a dry pipe valve was involved, or leaking valves in drain lines. If a reporting system was as complete for all DOE entities as it was for some of the respondees, many more incidents would have been included. However, the damage reported would have increased insignificantly.

The reported incidents, including the largest, include several where the loss occurred during test or while the system was still under warranty. Even though the dollar loss may not have been suffered by DOE, the total is still included in this summary.*

The following sections break down the data for each of three major system types by cause (Sections 2 through 4); and for each of four major causes by system type (Sections 5-8). A section expounding on the no-loss incidents (Section 9) and a section on faulty equipment (Section 10) are also included. Data relating to frequency-severity analysis was already presented in Section A17. Notes on comparative reliabilities form Section 11.

Since non-fire incidents include the most trivial, the data submitted was most extensive for the most recent years. Unlike fire data, reports of minor damage to sprinkler systems will not be retained for more than a few years. Thus, the plot of Frequency of Reported Incidents (B1) does not indicate an increase in the number of incidents occurring, only that records were not available for more than about a 5-year period. (Some increase undoubtedly occurred, due the increase in number of installed systems, but it should be more in line with the modest increase in sprinkler fires shown on the same plot.)

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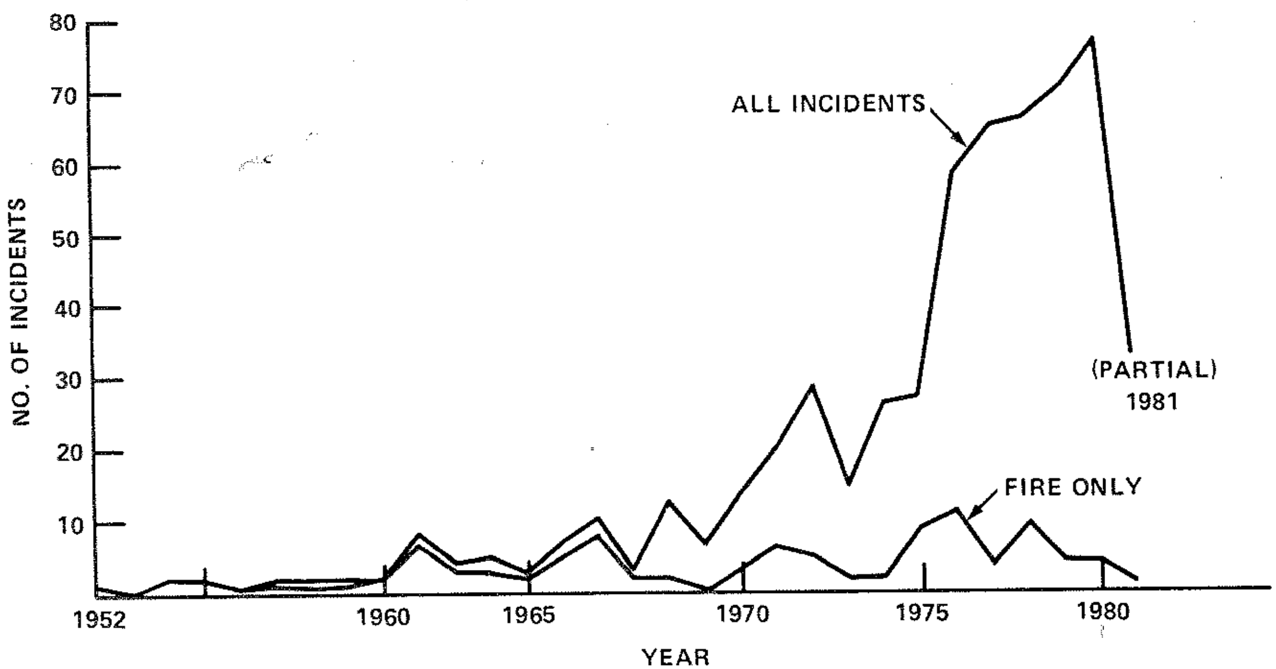
*Of only 13 losses exceeding $5,000, 4 occurred under test. The largest, included as $96,000, may not exceed $46,000 as of March 1982. Thus, the data included in this section is very conservative.



FREQUENCY OF REPORTED INCIDENTS

B2 Non-Fire Incidents by Cause - Wet Pipe Systems

The wet pipe sprinkler system is by far the most predominant type of sprinkler system in DOE. About 81 percent of the fire incidents were in wet pipe system areas and this is believed to be about right for the ratio of wet pipe to other systems; i.e., something over 80 percent of the total of DOE sprinkler systems are wet pipe systems. In terms of non-fire incidents, the wet pipe system was involved in fewer incidents than would be expected. This tends to confirm the DOE design criteria whereby wet pipe systems are the primary choice for simplicity, maintenance and reliability.

Since the vast majority of DOE systems are wet pipe, the number of incidents is large. There were 278 non-fire incidents involving wet pipe systems. This was 59 percent of the total. The 278 incidents, as shown by Table A2, accounted for $202,017 in losses, for a mean loss of about $727.

The number of "no loss" incidents reported was very high, 53 percent of the total ("no loss" incidents are discussed further in Section B9). If a minimum of $25 were arbitrarily assigned to any loss, the median would only rise to $740 per incident. As discussed under the fire summaries, the effect of the few large losses overshadows any effects from reasonable changes to the frequent, but low-loss incidents.

The maximum loss was $96,000 (see Section B10), the result of leaks during overnight hydrostatic testing of a new system resulting in damage to computer equipment.

The major cause of loss was freezing, accounting for over half of the total number of incidents, although constituting only one of seven causes.

The overheat incidents were some of the most significant. Most of these involved the actuation of one sprinkler head. While accounting for 21 percent of the number of incidents, they accounted for only 1 percent of the damage. In fact, 54 percent (32 of 59) of the incidents resulted in no damage, and the maximum was only $300.

The low losses resulting from accidental discharge seems to be belied by the "leak" category. However, if the computer incident is deleted, the mean of the remaining 17 incidents is only $208.

Faulty equipment resulted in a disproportional loss compared to the frequency, the 4 percent of the incidents resulted in 10 percent of the loss. This category is discussed further under Section B11.

B2

NON-FIRE INCIDENTS BY CAUSE WET PIPE SYSTEMS

Cause	No.	%	$Loss	%	No. of $0 Losses	% of Cause	$Mean	$ Maximum	(Revised)* Mean
Freeze	149	54	72,176	36	81	54	484	22,000	498
Overheat	59	21	2,812	1	32	54	48	300	61
Mechanical	32	12	7,396	4	13	41	231	2,600	241
Leak	18	6	99,538	49	12	67	5,530	96,000	5,547
Faulty Equip.	10	4	19,995	10	4	40	1,996	14,795	2,010
Corrosion	7	2	100	0	4	57	14	50	29
Unknown	3	1	0	0	3	100	0	0	0
Total	278	100	202,017	100	149	54	727	96,000	740

* Assuming minimum cost was $25.00

B3 Non-Fire Incidents by Cause - Dry Pipe Systems

Freezing is also the predominant cause of damage to dry pipe systems. Freezing occurs most often in drain legs, test valves and similar locations where water is expected to collect. It appears that more thorough routine inspections should prevent most of these incidents.

Several freeze incidents involved piping not properly pitched.

The freeze incidents also predominate in the losses. While the 34 incidents constituted 59 percent of the number of incidents, they resulted in 91 percent of the property damage, even though there were 15 freeze incidents that reported "no loss."

Again, the number of "no loss" incidents is significant, 55 percent of the total. Even if a minimum loss of $25 was charged to every incident, the mean damage to (or from) a dry pipe system increases only from $1,023 to $1,037.

The largest single loss, $20,000 resulted from freezing. As with the largest wet pipe system loss, this was an installation error. A new system installed in November 1978 was mistakenly left wet overnight. The system was not complete and alarms were not yet in service when a freeze ruptured a number of pipe joints. The $20,000 was estimated as the system had not yet been accepted and there was no actual loss to the government.

B3

NON -FIRE INCIDENTS BY CAUSE - DRY PIPE SYSTEMS

Cause	No	%	$ Loss	%	No. of $0 Losses	% of Cause	$ Mean	$ Maximum	(Revised)* $ Mean
Freeze	34	59	53,923	91	15	44	1,586	20,000	1,597
Overheat	8	14	4,600	8	5	63	575	4,000	591
Corrosion	8	14	250	0	7	88	28	250	53
Mechanical	3	5	350	1	2	67	117	350	133
Leak	2	3	11	0	0	0	105	110	105
Faulty Head	2	3	0	0	2	100	0	0	25
Air Loss	1	2	0	0	1	100	0	0	25
TOTAL	58	100	$59,323	100	32	55	1,023	20,000	$1,037

*assuming minimum cost of correction was $25

B4 Non-Fire Incidents by Cause - Deluge Systems

There were 97 deluge system incidents, of which 78, or 80 percent resulted in no damage. This is more understandable as a number of the listed causes would simply result in an accidental trip and, on systems such as cooling towers, no damage would be expected.

The largest loss, $36,000 occurred in April of 1980 when a deluge system in a hot cell tripped for unknown reasons. About 2,000 gallons of water were released, resulting in high cleanup costs. Several earlier trips, in other locations, were caused by accidental impacts to manual release buttons/switches. Protective covers are universally applied to DOE systems now, and were in place here.

Several accidental trips to cooling tower systems resulted when pneumatic tubing was laid on the deck and was stepped on by workers.

The next largest loss, of $6,254 resulted from a freezeup of a small filter bank deluge system in January 1977. Some water was discharged on thawing and contamination cleanup was the major portion of the loss.

B4

NON-FIRE INCIDENTS BY CAUSE - DELUGE SYSTEMS

Cause	No	%	$ Loss	%	No. of $0 Losses	% of Cause	$ Mean	$Maximum	(Revised)* $ Mean
Overheat	23	23.7	250	0.5	20	87	11	100	33
Electrical	19	19.6	0	0	19	100	0	0	25
Air or N_2 Loss	11	11.3	0	0	11	100	0	0	25
Corrosion	5	5.2	1,160	2.1	1	20	232	500	237
Mechanical Impact	3	3.1	10	0	2	67	3	10	20
Human Error	4	4.1	5,581	10.1	2	50	1,395	4,500	1,407
Freeze	3	3.1	8,272	14.9	1	33	2,757	6,254	2,766
Misc.	9	9.3	1,300	2.3	6	67	144	1,200	161
Unknown	20	20.6	38,959	70.2	16	80	1,948	36,000	1,968
TOTAL	97	100	55,532	100	78	79	$572	$36,000	$593

*assuming minimum cost of correction was $25

B5 Freeze Incidents by Type of System

Table B5 summarizes the data for all freeze incidents according to the type of sprinkler system affected.

Damage to wet pipe systems accounts for 74.5 percent of the number of losses, as might be expected. However, wet pipe systems are estimated to constitute over 80 percent of the total number of sprinkler systems in DOE. Wet pipe systems also accounted for only 60 percent of the damage.

The dry pipe systems experienced 16.8 percent of the number of incidents and accounted for 24.4 percent of the loss. Since the primary purpose of the dry pipe system is to avoid the freeze potential of other systems, this would seem to be a surprising disproportion. However, as noted in Section B3, such a system will accumulate water from tests, or condense it from temperature-humidity changes. If piping is not pitched correctly (acceptance inspection fault) or not drained adequately after test and periodically for condensation (inspection/ maintenance fault), water will collect. Since the dry pipe system is installed where freeze conditions are the norms (many of the wet systems in DOE are in non-freezing climates), the disproportion may be more apparent than real.

The same conditions noted for dry pipe systems apply to deluge and pre-action systems.

Somewhat surprising, are the six incidents affecting anti-freeze systems. Since they are filled with an anti-freeze liquid, they should be the least susceptible to freezing. A review of the six incidents reveals that the second largest loss, $600, resulted when a valve leaked, allowing 12 feet of pipe to fill with water and freeze. The other incidents were all due to freezing of sprinkler heads (two heads in one case, a single head in the others). The largest loss, $883, resulted from an incident described as "head was only leaking, it did not open up" and we have been unable to verify if the anti-freeze mixture was incorrect, a water pocket at the head did not mix with the anti-freeze or if the heads were faulty. The heads could have lost the anti-freeze and then froze, from overheat, a faulty head head, or mechanical impact, so the single cause of "freeze" does not necessarily indicate the real problem.

The mean loss in freeze incidents was 5 times the mean of the second most costly class of incidents, mechanical damage, and the total damage was 15 times the total damage from the next 3 most common causes combined; overheat, corrosion, and mechanical impact.

Again, the larger losses overshadow the common incidents to the extent that assigning an arbitrary minimum cost to an incident does not appreciably change either the total or the mean costs.

FREEZE INCIDENTS BY TYPE OF SYSTEMS

System	No	%	$ Total Loss	%	No. of $0 Losses	System %	$ Mean	$ Maximum**	(Revised)* $ Mean
Wet	155	74.5	132,574	60.0	81	52	855	56,000 (22,000)	868
Dry	35	16.8	53,923	24.4	15	43	1,541	20,000	1551
Anti-freeze	6	2.9	1,683	0.8	2	33	281	883	289
Deluge	4	1.9	9,472	4.3	1	25	2,368	6,254	2374
Unknown	6	2.9	13,200	6.0	2	33	2,200	6,200	2208
Pre-action	2	1.0	10,000	4.5	1	50	5,000	10,000	5013
TOTAL	208	100	220,852	100	102	49	1,062	56,000** (22,000)	1074

* Assuming minimum cost of changing head was $25

** The $56,000 figure is believed to be due to a number of single day failures. The next largest wet-pipe system loss was $22,000.

B6 Mechanical Damage Incidents by Type of System

There were 46 cases of damage to sprinkler systems due to mechanical impact; the most typical being the materials handling equipment hitting piping or heads in a storage facility.

Wet pipe systems lead the list with 71.7 percent of the number of incidents and 77.3 percent of the damage, although 14 of the losses or 42 percent of the 33 reported incidents resulted in negligible loss. For mechanical damage incidents, the proportions of incidents was roughly proportional to the frequency of each type of system in DOE, except for a larger percentage for deluge systems.

The dollar loss paralleled the incident frequency with the notable exception of deluge systems where almost 20 percent of the number of incidents resulted in less than 2 percent of the dollar loss. This is understandable since the majority of deluge systems are installed on cooling towers where the water damage potential is minimal.

The mean loss for all incidents is just over $200, a consequence of the most common incident being impact with a single sprinkler head.

The maximum loss of $2600 occurred in a warehouse when a fork truck impacted the piping on an ordinary-hazard schedule, wet pipe system in April of 1980.

MECHANICAL DAMAGE INCIDENTS BY TYPE OF SYSTEM

System	No	%	$ Total Loss	%	No of $0 Losses	System %	$ Mean	$ Maximum	(Revised)* $ Mean	Heads** Only
Wet	33	71.7%	7,396	77.3%	14	42%	224	2,600	235	25 (76%)
Dry	2	4.3%	350	3.7%	1	50%	175	350	363	2 (100%)
Deluge	7	19.2%	160	1.7%	3	43%	23	50	34	0 (0%)
Pre-action	2	4.3%	37	0.4%	0	0%	19	27	19	1 (90%)
Unknown	2	4.3%	1,624	16.8%	0	0%	812	1,570	812	2 (100%)
TOTAL	46	100 %	$9,567	100 %	18	39%	$208	$2,600	$218	30 (65%)

* assuming minimum cost of repairs was $25
** number and % of mechanical damage incidents in which only a single sprinkler head was hit.

B7 Overheat Incidents by Type of System

Table B7 shows the 86 sprinkler actuations caused by overheat.

Of the 86 identified incidents, 79, or 92 percent involved only 1 head. Accidental steam leaks were the cause of 11 of the total, including 4 of the 7 multiple-head incidents. Two heads were the maximum involved in any single incident.

The mean loss was the lowest for any cause, only $36 per incident. This is partly due to the large number of "no-loss" incidents, 55 or 64 percent of the total. Even if a minimum charge of $25 is assigned to every incident, the mean loss increases to only $52.

The principal reason for the low mean is lack of a significant large loss, the maximum loss being only $500. This occurred in 1975 when a steam line broke and actuated two heads.

B7

Overheat Incidents by Type of System

System	No.	Percent	$ Total Loss	Percent	No. of $0 Losses	System Percent	$ Mean	$ Maximum	(Revised)* $ Mean
Wet	58	67.4%	2,740	89.1%	31	53%	47	500	61
Dry	4	4.7%	100	3.3%	3	75%	25	100	44
Anti-Freeze	1	1.2%	15	0.5%	0	0%	15	15	15
Deluge	20	23.2%	220	7.1%	18	90%	11	120	34
Unknown	3	3.5%	0	0%	3	100%	0	0	25
Total	86	100.0%	$3,075	100.0%	55	64%	$36	$500	$52

* Assuming minimum cost of changing head was $25.00.

Note: In seven instances, two sprinkler heads operated (five wet systems, one dry, one anti-freeze). In all other cases, one head operated. The mean loss in the two-head instances was $88.00, or the (revised) mean was $102.00. (There were four "no loss" incidents).

Steam leaks originated eleven incidents, including four of the seven involving two heads. The largest loss ($ 500.00) was a two-head, steam-actuated loss.

B8 Corrosion Incidents by Type of System

Table B8 lists the 20 identified corrosion incidents. Although the total is small, dry pipe and deluge systems are disproportionally represented, primarily since deluge systems have an actuating system subject to exposure, and both dry and deluge systems expose internal piping to humid or corrosive atmospheres.

The largest loss occurred in 1980 when acid fumes corroded a pilot head, tripping a deluge system protecting a filter bank.

As in the other categories a major portion of the incidents were reported as "no loss." Assigning a minimum of $25 to any loss, the mean loss per incident is still under $100.

In 40 percent of the incidents, it was a single sprinkler head or heat actuating device that corroded. The remainder involved piping, fittings, valves, and tubing.

CORROSION DAMAGE INCIDENTS BY TYPE OF SYSTEM

System	No	%	$ Total Loss	%	No of $0 Losses	System %	$ Mean	$ Maximum	(Revised)* $ Mean	Heads** Only
Wet	7	35%	100	6.6%	4	57%	14	50	29	5 (71%)
Dry	8	40%	250	16.6%	7	88%	31	250	53	1 (13%)
Deluge	5	25%	1,160	76.8%	1	20%	232	500	237	2 (40%)
TOTAL	20	100%	1,510	100%	12	60%	$ 76	$500	$ 91	8 (40%)

* assuming minimum cost of changing head was $25

** number and % of incidents in which only the sprinkler head (or H.A.D.) corroded.

B9 No-Loss Incidents

A large number of incidents were reported as "no loss" or "negligible." As with the fire losses, assigning an arbitrary minimum figure of $25 to any incident does not materially change either the total loss or the mean loss, since the effect of the few large losses is so predominate.

About half the "no loss" category used the word "negligible." This could refer to any loss under $500, the minimal non-fire reportable figure for many years. However, many losses were included at figures from $5 to $18, including some from sites also reporting "negligible" losses, so any actual loss was probably quite small. It is also obvious that most of these losses affected a single sprinkler so that the loss was limited to replacement of a head by the fire department.

There were 94 cases where freezing was identified as the cause, 40 of which were specifically identified as one-head incidents, and 50 as pipe or fittings.

The most common incidents were deluge system trips, 69 from a variety of causes being included. Since most DOE deluge systems are installed on cooling towers or outdoor electrical equipment, no loss would be expected from an accidental trip.

Overheat, all but two of a single head accounted for 46 cases, mechanical impact to a head, 10 and there were 6 unknown or miscellaneous incidents.

Four of the faulty head, or potentially defective head incidents reported no damage (See Section B10).

A number of the incidents would probably be considered maintenance items and not be reported under any reasonable system. From a review of the incident reports, and further discussions with a number of the submitters, the author concludes that the number of "no-loss" incidents would have been considerably higher if all sites had been equally thorough in their reporting system.

B10 Faulty Sprinkler System Components

The survey made a special effort to obtain incidents involving failures and to translate these into some form of reliability data. These are summarized below and in the attached table B10. (Sprinkler system estimates are detailed in Appendix B.)

There were six incidents in which a sprinkler head was reported to have failed. Four of the incidents resulted in no loss and the aggregate was only 1 percent of the losses from all 37 reported failures.

Utilizing only the number of sprinkler systems at those sites supplying the supplementary data, and excluding any years of experience prior to their first reported incident, the reported incidents cover about 30,000 sprinkler system-years of experience. Thus the failure rate is about one incident per 5000 system-years. If the average sprinkler system is assumed to contain 200 heads, this would be a failure rate of 1×10^{-6}. This agrees with the often quoted statement that the chance of a sprinkler head failing is about one per million heads per year.

There were seven incidents in which a head was identified as leaking. Generally the head was not identified and the reports were old enough such that it was not possible to ascertain if it was the head itself that leaked, or the threaded connection. Even if all involved the head itself, the actual cause could have been mechanical impact, freezing, sudden heat, or prolonged high temperature ("cold flow"). If it is assumed that all cases were actual head failures, the combined failure rate would be about 2.2×10^{-6}. Since it is possible that some of the cases reported as "failures" were also due to other basic causes, the lower figure is probably closer to the actual failure rate.

There were also 19 cases where pipe or fittings failed. These accounted for 99 percent of the loss. Almost all of the loss (87 percent) resulted from incidents during, or soon after testing and the loss was the sprinkler contractor's, not DOE's. The largest loss occurred during installation in an occupied computer area. Obviously, the major loss potential exists when retrofitting systems to occupied buildings.

There were five miscellaneous losses reported. These involved:

1. Breaking of a plastic plug in a check valve.
2. A design fault in a light water foam deluge system selector valve that allowed 20,000 gallons of foam to discharge. (The vane-type waterflow device also failed in this incident.) The cost was reported as the cost of running the evaporators in the cleanup system and was considered negligible (cost of foam solution was not mentioned).
3. A mercury switch failure in a deluge system.
4. A faulty check valve discovered in a new installation.
5. A water flow switch gasket failed after initial installation, allowing the switchbox to blow out. Damage was $3500 (no DOE loss-system under warrantee).

For all incidents combined, the total loss was about 25 percent of the total non-fire damage, and the incidents included in this category total less than 10 percent of the number of incidents resulting in damage to, or from, sprinkler systems. In over half the cases, the leaks were small and resulted in no damage.

Factory Mutual Loss Prevention Data Sheet 10-24 of June 1961, reported that sprinkler leakages of all types made up only about 4 percent of FM losses and the unexplained operation of sprinkler heads was an insignificant fraction of the 4 percent. DOE experience conforms to FM's. The $121,953 total of the cited DOE incidents is less than 3 percent of the combined fire and non-fire DOE experience and the loss from the 13 sprinkler head incidents is about 1 percent of the faulty components losses and about 0.3 percent of the total non-fire incidents. (Seventeen percent of the FM losses were from breakage of buried mains, which are not included in this study. However, the balance does not significantly affect the above.)

There are three incidences of defective heads not included in the above, namely:

1. In 1968, there were several negligible loss incidents involving defective sprinkler heads in a new building at Lawrence Livermore National Laboratory. These were due to a manufacturing defect and all were replaced by the manufacturer (see Underwriter's Laboratories December 9, 1968, memorandum to Insurance Inspection and Rating Bureaus regarding Reliable Issue C, 160°F Temperature Rated Sprinklers).

2. In 1971, a number of Globe "G", 1968-69 series heads were determined by the manufacturer to have a potential defect. A number of these were installed in various DOE facilities and three had opened accidentally at one laboratory. There were 1200 heads replaced at that facility, as well as a number at other facilities.

3. When the "on-off" type of head first became available, a number were installed in various DOE facilities. Some systems experienced trouble in seating of the heads in initial installations, particularly when inappropriately installed in dry pipe systems. Some locations replaced the heads and others experienced no problems after initial installation.

In some aspects, the above data is either understated or overstated. Reports to insurance companies would not normally include "no loss" incidents, or incidents occurring during the acceptance testing of systems; examples of both of which are included in the DOE data. On the other hand, there are a number of system faults included in DOE reports that are not included in this section, particularly spurious deluge system trips (loss of air or nitrogen pressure, etc.) that resulted in no loss. Also, there undoubtedly were a number of minor head or piping leaks in DOE systems that were considered so insignificant that they are not even included in these reports.

An estimate by one Factory Mutual Senior Research Scientist in 1977 stated that the probability of premature sprinkler operation due to manufacturing defects was about 0.06×10^{-6} per year, and, from all causes about 1.6×10^{-6} per year. The second figure is quite close to DOE experience, if "no loss" incidents are omitted, and the first is within a factor of five if the "no loss" incidents are omitted. This again confirms the validity of the usually quoted range of reliability figures.

There is another category of DOE incidents, not included above, that are worthy of note. That is incidents of known defects, or problems, that resulted in no losses or outages. As an example, a 1979 manufacturers notice discussed a problem with mercury check valves used in a number of zoned deluge systems. All DOE systems incorporating these devices were inspected and a number were replaced, but none had failed or exhibited the defect to any major degree.

Another example relates to closed-head sprinklers installed in cooling towers, years before the NFPA standard was first adopted in 1959. A type of corrosion was discovered in which the sprinklers were effectively welded shut, although the outward appearances of corrosion were negligible. The general plant upgrading projects in DOE facilities have long since replaced these systems with deluge systems, and there were no instances where the defective heads were involved in fire.

FAULTY SPRINKLER SYSTEM COMPONENTS

	No	%	$ Loss	%	No. of "No-Loss" Incidents	% "No Loss"	Failure Rates* System-years Per incident	Failure Rates* Heads per year
Sprinkler head "failed"	6	16%	1,180	1%	4	67%	5000	1×10^{-6}
Sprinkler head "leaked"	7	19%	70	0%	4	57%	4300	1.2×10^{-6}
Sub-Total	13	35%	1,250	1%	8	62%	2300	2.2×10^{-6}
Pipe or fitting failure	19	51%	117,203	96%	9	47%	1600	
Miscellaneous	5	14%	3500	3%	4	80%	6000	
Total	37**	100%	121,953	100%	22	59%	800	

*Based on 30,000 system years. At 200 heads per system 30,000 system years = 6,000,000 head years

Of the 37 failures, 6 occurred during or, as a consequence of, acceptance testing. These accounted for $102,500 or 87% of the total losses reported, most of which was not suffered by DOE.

B11 Sprinkler vs. Other System "Water Damage" Incidents

Data on damages involving sprinkler systems in non-fire incidents can be very misleading in that it omits one of the fundamentals of systems analysis, namely: "Compared to what?"[1] The large number of non-fire incidents in this study can lead to an erroneous conclusion unless they are compared with damages from other water systems.

The loss reporting system in DOE has included all types of property damage, regardless of cause or effect, based only on the fact that damage was incurred. Since 1975, the minimum level reported to the Headquarters system was $1000 and was based solely on the estimated replacement cost of any equipment damaged, whether or not it was actually replaced. (Costs of cleanup, added labor expenses, etc., are also included.) Thus there has been a considerable body of experience, all calculated in the same manner, from which some valid comparisons can be made. This was done in 1975, and upgraded again in 1980. Table B11 and the following are quoted from the 1980 study.[2]

Water Damage Incidents

The 1975 Annual Summary Report contained an Appendix E giving a statistical summary of water damage losses since 1970. That table is repeated here, together with an update for the years 1976 through the first quarter of 1980 and a combined summary of all reported incidents since 1970.

The 1975 report stated: "The potential for water damage is often used as an argument against the installation of automatic water sprinkler systems. However, it is seldom used as an argument against the installation of other water systems." The new data confirms the essential reliability of the fire protection systems.

"Water damage," as a category contains some of the oddest DOE accidents. There have been several "water damage" losses in which the principal loss was fish and one in which the only thing damaged was--water! The fish losses occurred when experimental fish tanks were damaged by pipe breaks (overflowing, contaminating or physically ejecting fish). The water damaged was heavy water diluted by ordinary water entering a vent, requiring reprocessing to recover the "diluted water" at a cost of $6,200. These losses are included as "other" losses in the DOE reporting system and are not included in the table.

Reportable minimum loss is $1,000 so the low of $1,081 is not a true minimum. Maximum loss was $23,992 when process water leaked through septifoil valves into a reactor tank. The maximum loss from a fire protection system was $22,000 when a number of sprinkler system freeze-ups occurred as a result of heating failures at one facility. Principal damage was to the sprinkler systems themselves.

The overall severity of loss from a fire protection-related system is half the severity from a non-fire protection water system ($3,097 vs. $6,375). As noted in the 1975 report: "The difference is due to the fact that fire protection systems are required to have waterflow alarms connected to a fire department. Other water systems cannot usually be provided with leak detectors and leaks are not immediately reported to a plumbing shop on duty 24 hours a day."

In terms of major losses, the difference is even more pronounced. There were two sprinkler losses exceeding $10,000 and six non-fire system losses over that amount.

The major "water damage" losses are not included above. There were at least eight rain and flood incidents (including a $250,000 loss) not included and several snow, ice and hail losses (including one of $174,300).

Several losses also resulted from leaks of heavy water, due solely to the value of the material. These also are omitted in the table.

Cause

Freezing is the most common cause. A typical scenario is the failure of a building heating system for a sufficient time to allow water in pipes to freeze and break the pipe or fittings. If the damage is not detected before thawing, subsequent leaks may damage other materials.

In the 1976-1980 period causes are classified as:

Freezing	- 19
Ground shift or settling	- 8
Leak in system component	- 8
Mechanical impact (bumping)	- 3
Pipe, valve, or vent open	- 3
Faulty valve seal	- 2
Pressure failure of pipe	- 2
Miscellaneous	- 6
Unstated	- 1

The data in this report differs from the above due to the inclusion of a large number of small damage losses in this sprinkler study, for which there are no comparable data for other systems. Losses not suffered by DOE, for either sprinkler or non-sprinkler water systems are also omitted from Table B11, although a number are included in other sections (see Appendix E, for example).

It should also be noted that the basic cause of a "sprinkler loss" is frequently due to another accident. Examples abound in this study where the precipitating cause was heating system failures, steam leaks, materials handling accidents, and acts of nature (wind breaking windows or opening doors in freezing climates, etc.). Many of the sprinkler losses were only a part of other losses, especially the freezing incidents.

Again the superior performance of sprinkler systems, as opposed to other water systems, can be attributed to several factors, as follows:

1. Sprinkler installation is a separate mechanical trade. Workers installing only sprinkler systems gain more experience and expertise than general contractors.

2. Inspection and test requirements are more rigid (the most common sprinkler hydrostatic test is 200psig for 2 hours with no allowable leaks) and sprinkler systems are probably tested/inspected more universally than ordinary water systems.

3. Water does not normally flow in a sprinkler system, thus the common "wear and tear" of valves, fittings and pipes is largely eliminated.

4. Accidental leakages (through mandatory waterflow alarms) directly notify the proper authority (at most DOE sites, an on-site fire department), thus limiting damage when it does occur.

The last item illustrates an unexpected advantage of sprinkler systems in areas containing other water systems. In effect, the sprinkler system is a low-cost freeze detector!

[1] The three questions, expounded by Dr. P. Beckmann are: "Who says so? Compared to what?, and If not, then what?" They are used in his book: "The Health Hazards of Not Going Nuclear, Golem Press, Boulder Colorado, 1976.

[2] DOE/EV-0053/1 Summary of Property Damage Control Programs of The United States Department of Energy CY 1979, available from NTIS.

B 11

Water Damage Incidents

		Sprinkler Syst.	Other Fire Syst.	Total Fire Systs.	NonFire--Prot. Water Systs.	Combined Total
1970-1975	Number	16	6	22	26	48
	$Loss	$23,766	$11,017	$34,783	$170,360	$205,143
	Average	1,485	1,836	1,981	6,552	4,274
1976-1980 (1st Qtr.)	Number	18	6	24	27	51
	$Loss	$92,822	$14,834	$103,656	$157,534	$266,790
	Average	5,157	2,472	4,319	5,835	5,336
Combined 1970-1980	Number	34	12	46	53	99
	$Loss	$116,588	$25,851	$142,439	$337,894	$471,933
	Average	3,429	2,154	3,097	6,375	4,767

C1 Value of Sprinklers to DOE

The value of sprinkler systems is clearly shown in preceeding Sections. While the benefits of sprinklers are hardly a new discovery, one aspect is especially noteworthy--that is benefit despite the low fire losses achieved by DOE programs. The fire losses from all causes in all of DOE in just the last 6 years have been over $50,000,000 less than would be expected in the same period, if DOE was equal to the "improved risk" class of insured industry. (See Table C1.)

The "improved risk" insurance includes some things other than fire, and some DOE fire losses include fires not insured under the "improved risk property insurance policies, so the comparison is not exact.

A more dramatic figure is to compare all DOE losses against the best insurance rates. On this basis, even assuming such items as transportation, contamination, mechanical (boiler and machinery), earthquake, etc., were included in the best "improved risk" rate of about 5¢ per $100 of insured value, DOE's total losses are $30,000,000 less than the insurance premiums would have been in just the last 6 years.

The low rate of fire losses in DOE makes the lessons learned from DOE's sprinklered fire losses even more dramatic. The Paducah fire, in which a sprinkler fire could be compared directly to a similar earlier fire, plus a second diffusion plant fire and a cooling tower fire total about $120,000,000 in direct loss reduction due to sprinklers, or more than enough to have paid for every sprinkler system installed in DOE history. Even more important, the intangible losses that would have resulted from many of the sprinkler fires, if the sprinklers had not been present, undoubtedly far exceed mere dollar impact. These include the vital areas of loss of production capability, personal injury and, perhaps above all, public impact. Thus, sprinklers in DOE have not only paid for themselves, they have been one of the best investments.

C1

Cumulative Savings

Year	Replacement Value ($M)	Fire Loss ($)	Total Loss ($)	Loss at 2.7¢/$100 "Improved Risk" Rate ($)	Savings($) Fire Only	Savings($) Total Losses
1975	31,658.3	766,868	5,252,349	8,547,741	7,666,868	3,295,392
1976	35,512.7	251,849	2,292,876	9,588,429	9,336,580	7,295,853
1977	39,856.1	1,084,823	3,613,984	10,761,147	9,676,324	7,147,163
1978	47,027.1	12,976,036	17,477,979	12,697,317	(-) 278,719	(-)4,780,662
1979	50,240.8	654,716	2,541,023	13,565,016	12,910,300	11,023,993
1980	54,654.7	1,385,686	8,545,935	14,756,769	13,371,083	6,210,834
				Total Savings	$52,682,437	$30.192,573

Note: If every category of loss, including vehicle and brush fires, earthquake, contamination and transportation losses were able to be included in an "improved risk" insurance policy at the lowest rate of approximately 5¢/$100, DOE would have paid approximately $90 million more in premiums than were sustained in losses.

C2 Conclusions

The following reiterates some of the more general and more important conclusions resulting from the study. Parenthetical numbers refer to the Sections supporting the conclusions.

1. The losses from fires in sprinklered facilities are one tenth of the loss from all fires. Considering only building fires, sprinklers reduce the loss by at least a factor of 5. (A9)

2. The damage to, or from sprinkler systems is one tenth of the fire loss in sprinklered fires, or one fiftieth of the fire loss in all buildings, or one-hundredth of the total fire loss. (B1)

3. Sprinkler systems are more reliable than non-sprinkler water systems. Both the frequency of, and the mean loss from, non-sprinkler systems are about twice that of sprinkler systems. (B11)

4. Sprinkler systems are over 98 percent effective in controlling or extinguishing fires. (A2)

5. The wet pipe sprinkler system is the most effective and most reliable type of system. (A3, A5, B2)

6. The chance of a sprinkler head failing is about one in a million per year. (B10)

7. The chance of any failure in a sprinkler system is about one per year for every 800 systems. (B10)

8. Thorough inspection, test, and maintenance procedures can eliminate most causes of sprinkler failures, in either fire or non-fire situations. (A7, B2, B10)

9. Standard (spray) sprinkler heads are more effective than old-style (pre-1953) heads, but there is little or no difference in overall system performance. (A16)

10. Freezing is the most common cause of all sprinkler system losses, including dry pipe systems. (B3)

11. About one third of all fires may be completely extinguished by only one sprinkler head operating. Less than one fire in ten will activate as many as six heads. (B2)

12. Sprinklers are extremely sensitive to ceiling height. In high-ceilinged areas, both the mean loss and number of heads actuated may increase by an order-of-magnitude.

13. Previous experience may not be a reliable predictor. The typical fire involving a sprinkler system is small enough in its consequences that the rare but large loss will distort all prior experience. (A10, A11, A12, A13, A17)

14. A functionable automatic sprinkler system is an excellent life-safety system. (A14)

15. Structural analysis/design of piping, bracing, hanging systems is not warranted for the majority of installations. The NFPA 13 code requirements are adequate, including earthquake bracing. (A18)

16. The most probable fire loss in DOE, in which a sprinkler system controls or extinguishes the fire, is about $55,000. This includes the effect of the rare, large losses. (A17)

17. The most probable loss, to or from a sprinkler system, in a non-fire incident is about $1100. This includes the effect of the rare, but large losses. (A17)

18. Within the DOE fire protection system, a fire loss of $1,000,000 or more can be expected about once in 30 years in sprinklered occupancies and once in 4 years in other areas. (A11)

19. Within the DOE fire protection system, a non-fire incident, involving sprinkler damage of $100,000 or more, can be expected about every 25 years. A $1,000,000 loss appears to have a 200 year frequency; however, this is too far beyond the experience projection to be a credible predictor. (A11)

C3 Recommendations

The following recommendations are intended to provide guidelines for sprinkler system application and analysis in DOE facilities.

1. As the most effective, reliable, and cheapest form of protection for sizable fire risks is the automatic sprinkler system, it is the primary protection system for DOE facilities.

2. As the wet pipe sprinkler system is the most effective, reliable, and cheapest form of sprinkler protection, it is the preferred system for installation in DOE facilities.

3. Installation of sprinklers throughout the potential fire area should take precedence over the provision of alarm systems, large capacity or high-flow water supplies, area subdivisions, or manual capabilities.

4. Risk analysis must include more sophisticated techniques than analysis of past experience. In addition to considerations of maximum potential loss, extreme value projections and frequency-severity studies should be used to define past experience and predict future trends.

5. Hydraulic design should be utilized where savings in pipe sizes/lengths may result and when such design can obviate the need for additional or stronger water supplies. Hydraulically designed systems (unless specifically required by code for certain occupancies/contents) should not routinely replace pipe schedule systems.

6. Piping, hangers, and bracing should conform to NFPA 13 standards. In particular, structural analysis and engineering design of hangers and bracing is not required to ensure adequate earthquake protection.

7. In addition to normal requirements for acceptance testing, systems newly installed in occupied facilities should receive daily before-work status inspections and close-of-work shutdown inspections.

8. All modifications to building heating, ventilating and air conditioning systems (including planned changes to operating settings) should receive prior review by knowledgeable fire protection personnel.

Appendix A

Survey Method and Background

The performance of automatic sprinkler systems has been evaluated almost since the first widely-used sprinkler, the third model Parmalee head, was developed in 1878. Thirty successful operations in mill fires had been recorded by Factory Mutual by 1882.[1] By 1884, some 128 fire operations had been recorded.[1] At the National Fire Protection Associations first meeting, in 1897, a report on 205 sprinklered fires was delivered,[2] and by the time that Gorham's classic book on sprinklers was first published in 1914,[3] thousands of fire experiences had been recorded.

Through the years, the National Fire Protection Association has published a number of statistical summaries. In general, the performance record seemed to indicate continuing improvements, culminating with the Australian-New Zealand experience reported by Marryatt in 1971.[4]

In recent years, interest in sprinkler performance was heightened by the trade-offs in construction features under the national building codes. Concurrently, several sources noted an apparent decline in sprinkler performance in articles questioning the justification of trade-offs.[5]

The subject of sprinkler performance and reliability was discussed at several DOE Fire Protection Engineers annual conferences. Most attendees felt that overall performance was considerably better than some reports indicated, primarily because few data-gathering agencies had access to every operation, particularly when only one sprinkler head was involved or the dollar loss was minimal. All felt that DOE sites should be able to accumulate more complete data since almost all major sites have fire departments and professional fire protection engineers on site. Accordingly, it was agreed that an effort would be made to compile DOE-wide data.

A survey form was prepared with the objectives of making the form as simple as possible; not exceeding one page; preferably in a "checkoff" format; and including non-fire incidents. The draft form was sent to the field offices for comment and a revised form distributed for use on January 15, 1981. This inquiry resulted in some 507 responses from 25 sites, some providing data for as much as 21 years experience.

At the same time, all records from AEC/ERDA/DOE experience available in DOE Headquarters, including dead file storage, were reviewed, and this enabled additional incidents dating back to 1952 to be added to the author's list.

The final collection of nearly 600 items included only 115 fires but these provided a wealth of information. The more than 400 non-fire incidents were particularly valuable in that they enabled some analyses to be made on the bases of the number of systems involved, over a multi-year period, and thus form at least an initial step in evaluating reliability as well as performance.

[1]Able Men of Boston, 1850-1950, Dane York, Boston Manufacturers Mutual Fire Insurance Company, 1950.

[2]Men Against Fire, The Story of the National Fire Protection Association, 1896-1971, Percy C. Bugbee, NFPA, 1971.

[3]Automatic Sprinkler Protection, Gorham Dana, John Wiley and Sons, 1914, (Second Edition, 1919).

[4]Fire-Automatic Sprinkler Performance in Australia and New Zealand, 1886-1968, H. W. Marryatt, Australian Fire Protection Association, 1971.

[5]Sprinkler Trade-Offs: Are They Justified? James P. Barris and Dario L. Conte-Russian, NFPA Fire Journal Volume 74, No. 3, May 1980.

(2-79)

Wash., DC. 20545

U.S. DEPARTMENT OF ENERGY

memorandum

DATE JAN 15 1981

REPLY TO ATTN OF EV-134

RECEIVED JAN 27 1981 NPR-3-WYO

SUBJECT Automatic Sprinkler Survey

TO Those on Attached List

Attached are copies of the automatic sprinkler survey form, revised to incorporate field office comments. Please distribute copies to each sprinklered facility under your jurisdiction that you consider to have had applicable experiences.

The form is intended to be used by each DOE site to record all past sprinkler operations at their site, regardless of cause or amount of loss. To simplify the compilation, a single page is used with most data elements completed by simply circling the appropriate words. Forms should be sent directly to Walter Maybee for compilation.

All incidents readily available to the originators should be reported. However, where some incidents may only be available from destroyed or dead storage records, it is not necessary to try to reconstruct or retrieve the records. Since this is a one-time survey, as many incidents as possible are desired, regardless of the date of occurrence. For some incidents, only partial information may be available but these should still be included in the responses.

Since a number of facilities have had no reportable incidents and the total number of forms required is unknown, each facility should make sufficient copies of the blank form for their own needs.

Forms should be submitted to W. Maybee by May 30, 1981. Data will be compiled and issued as a separate document by Safety Analysis Branch by mid-August and a summary will also be included in the CY 1980 issue of DOE/EV-005 3/2, "Summary of Property Damage Control Programs of the United States Department of Energy, CY 1980." Data will also be used as input to the U.S. Fire Administration and other interested parties.

R. P. Prichard

Reuben P. Prichard, Chief
Safety Analysis Branch
Operational and Environmental
Safety Division

Attachment

contact ______________ at FTS __________.

W. Maybee, EV-134
Dept. of Energy
Washington, D.C. 20545

Sprinkler Operation Survey

Fill in blanks and circle applicable words. Use separate sheet for each incident.

Date of incident ______________ $Loss(1) ____________ (Fire ________ Water ________ Other ________

Type system: Wet; Dry; Preaction; Deluge; Other ______________.

System design: Light; Ord; Extra Hazard; Calculated (under 0.2 density); Calculated (over 0.2 density); Unknown; Other ______________

Number of heads/nozzles operated __________; Number of systems operated _________; Unknown.

Type of heads: Old style (Pre-1954); Spray (Post-1954); Spray nozzles; Other ____________; Unknown.

Temperature rating: 212°F or under; Over 212°F; Open heads/nozzles; Unknown.

On-site Emergency Organization: Did; Did not; Respond to water flow alarm; Other alarm; No on-site emergency organization.

Off-site or Mutual Aid: Called; Not called; None available.

Fire Incidents (Only those fires involving sprinkler operation)

Height of sprinklers above floor: Less than 10'; Over 10'; Unknown.

Effect of sprinklers: Extinguished fire (no other agents used); Controlled fire (other agents used); Failed (explain under comments).

Other agents (if used): Portable extinguishers by occupants, fire department; Hose streams by occupants, fire department; Other ____________.

Occupancy of fire area: Office; Storage; Lab; Shop; Manufacturing; Hot Cell; Reactor; Accelerator; Isotope separation (including GDP); Mechanical; Electrical equipment room; Computer; Cooling tower; Transformer or switch gear (outside); Other (specify) ________________.

Occupancy of building: ____.

Fire area was: Radiation area; Non-radiation area.

Building: Fully sprinklered; Part sprinklered(2).

Fire originated in: Sprinklered area; Unsprinklered area.

Fire cause (if known): ____.

Principle conbustible involved: NFPA Type A; B; C-A(3); C-B; D.

Non-Fire Incidents (Include overhead sprinkler or piping ruptures but not underground pipe breaks).

Cause: Faulty head; Freeze, rupture of heads, piping; Mechanical impact to heads, piping; Overheat; Accidental trip of deluge system; Pipe joint failure; Water admitted to open system (repairs, etc.) cutting or welding; Vandalism; Unknown; Other (specify) ____________________.

If faulty equipment: Make, model, rating, etc. ______________________________.

Explanations or Comments

____

____

____.

1. List total loss. Include fire-water-other breakdown only if significant and note unusual factors in comments.

2. If building partly sprinklered, note under comments whether or not unsprinklered area was a factor in the amount of damage suffered.

3. C-A is computer, air breaker, power line, etc. C-B is oil transformer, etc.

Appendix B

Number of Sprinkler Systems in DOE

As of the date of the survey, there were approximately 4200 sprinkler systems in DOE facilities, the vast majority existing in the government-owned, contractor-operated plants formerly part of the Atomic Energy Commission.

The largest number of systems at a single site is in excess of 500, at the Oak Ridge Gaseous Diffusion Plant. The three uranium enrichment plants, together, account for about one-forth of all the sprinkler systems in DOE.

To establish a base number for use in reliability, only the sites supplying the supplementary (including "no-loss" incidents) data were included. These sites had 3200 systems, or about three-quarters of the total. Also, to establish sprinkler-years, only the years for which actual data were submitted are included. That is, no credit is given for any years of incident-free operation prior to the year of the first reported incident. Since the major losses and incidents for all sites are included, and some sites had several years of incident-free operation, the calculated reliability data is probably somewhat worse than the actual.

The number of systems also varied. Since 1966, at least 1408 sprinkler systems were installed in upgrading programs. New buildings were also built and the sprinkler systems in those are not generally included in this total. At the same time, a number of facilities were closed down and the total number of systems in those facilities is not known, although the reportable losses that occurred at those facilities are included.

With the above considerations in mind, the best estimate of just under 30,000 system-years of experience formed the basis for the data in Part B of this report.

Similarly, data on the number of heads must be estimated. Several approximations were made on the basis of approximate heads per system, size of sprinklered areas and average square feet per head, and some actual sprinkler counts. The selected average of the estimated amounted to about 4.7 million head-years of experience, corresponding to an average of about 155 heads per sprinkler system. In this case, a large number of small systems (trailers, small cooling towers, transformers, etc.) was offset by the diffusion plant systems where the average is closer to the 400 heads per system maximum.

As of 1980, the major sprinklered DOE facilities are:

<u>Over 500 Systems</u>

Oak Ridge Gaseous Diffusion Plant, Oak Ridge, TN

Over 300 Systems

Y-12 Plant, Oak Ridge, TN
Los Alamos National Laboratory, Los Alamos, NM
Portsmouth Gaseous Diffusion Plant, Portsmouth, OH
Richland Site, Richland, WA

Over 200 Systems

Paducah Gaseous Diffusion Plant, Paducah, KY
Idaho National Engineering Laboratory, Idaho Falls, ID

Over 100 Systems

Sandia National Laboratory, Albuquerque, NM
Oak Ridge National Laboratory, Oak Ridge, TN
Nevada Test Site, Las Vegas, NV
Pantex Plant, Amarillo, TX
Argonne National Laboratory, Argonne, IL
Lawrence Livermore National Laboratory, Livermore, CA

Every type of sprinkler system is included in DOE, including multi-cycle systems and low-differential dry-pipe systems.* Sprinkler heads run the gamut of all conventional types, sizes, and temperature ratings and include on-off heads and a special clip-on attachment to convert fuse link assemblies to higher temperatures, developed for AEC by Factory Mutual.

*The Low-Differential Dry-Pipe Sprinkler System by Wayne Ault, Fire Journal, July 1965.

Appendix C

Multi-Head Sprinkler Fires

The following summarizes all sprinkler fires in which more than eight heads operated. About 95 percent of all the sprinkler fires involved 8 heads or less.

Paducah Gaseous Diffusion Plant 12-13-62

This fire is believed to have set the all-time record for the number of sprinkler heads to operate and control a fire. The original loss investigation listed 2,487 heads, including 57 on the cell floor level and 28 in exhaust ducts. Subsequent reports listed 2,341. Regardless of the actual total it is unlikely that any plant, other than a Gaseous Diffusion Plant, would have sufficient water to feed that many sprinklers.

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 over 2,000 sprinkler heads that operated during the 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 4 fire pumps of 4,625 gpm capacity at 125 psi each, taking suction from a 2,6000,000 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, while some hose streams were applied through holes in the siding by the plant fire department

The building, C-337 had over 1 million sq.ft. on a single floor, or 24 acres of Class II metal deck roof over one fire area. Some 18,000 sq.ft. of siding, 2,000 sq.ft. of roof deck, 30,000 sq.ft. of roofing, and 150 linear ft. of expansion joint had to be replaced. The plant was 90 percent back in service in 4 days.

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 a similar fire in a smaller, unsprinklered building at the same plant in 1956, that the loss in this building would have been in excess of $100 million.

Richland Garage Fire 11-21-78

This $243,000 fire was controlled by 149 sprinklers; all of the heads in the fire area.

A tank truck loaded with fuel caught fire in a bay of the Bus and Heavy Truck Maintenance Shop (Building 1171) on the Hanford site. The fire was initiated by a drop light which broke and ignited gasoline from a loosened flange on the fuel pump of the tank truck. Despite the destruction of the truck and the combustion of 1500 gallons of fuel (134 million BTUs), the sprinklers controlled the fire, resulting in only localized damage to the garage roof and nearby equipment. The remainder of the 112,000 square foot building and its contents were undamaged due to standard fire walls, operation of the ordinary hazard spaced wet pipe, sprinkler system and subsequent plant fire department efforts.

A mechanic suffered second-degree burns to the face, hands, and forearm.

Y-12 Plant 10-31-61

This garage fire resulted from ignition of 40 gallons of gasoline draining from a fuel tank fitting. The 34 sprinklers controlled the fire until the plant fire department completed extinguishment. Damage was limited to $302 government loss and $200 private loss.

Paducah Gaseous Diffusion Plant 1-3-78

On January 3, 1978, an electrical failure led to an explosion and fire in a high speed compressor in a UF_6 tails withdrawal facility at the Paducah Gaseous Diffusion Plant (OR). Twenty-five sprinkler heads, operated controlling the fire. Considering the Class II type roof (highly combustible) and the inability of the emergency squad to adequately combat the fire after the explosion because of dense, acrid smoke, the sprinkler system prevented total loss of the facility. The replacement value of this facility is $13 million. The wet pipe, hydraulically calculated system held the loss to $200,104.

All of the gaseous diffusion plant Class II roof buildings were sprinklered in the late 1950's at a total cost of $17,626,000. Since then, there have been several incidents in which the sprinklers prevented much greater losses. The most notable being a 1962 Paducah fire explosion in which the $2,900,000 loss would have been on the order of $160 million without the sprinklers.

Schenectady Naval Reactors 1963

Fire originated in rubberized horse-hair packing material in a storage area. The old style, dry pipe, ordinary hazard sprinkler system controlled the fire by 20 sprinklers until the plant fire department completed extinguishment. Loss was limited to the packaging material and considered negligible (less than $50).

Paducah Gaseous Diffusion Plant 12-13-76

A 2,000 HP process motor shorted and ignited during startup. Twenty sprinklers operated and controlled the fire while the plant fire department and operators completed extinguishment. Loss was $76,030.

Appendix D

Large Dollar-Loss Fires

Only 5 of the 115 fire-losses involving sprinklers exceeded $100,000 in cost. While constituting 4.3 percent of the number of incidents, they accounted for $3,742,904 or 85 percent of the total loss. The largest fire, alone, accounted for 65.9 percent of the total loss from the 115 fires (see Section A10).

These fires are described below, in chronological order:

<u>12-13-62</u> The Paducah Gaseous Diffusion Plant fire involved over 2,000 operating sprinklers and resulted in a $2,900,000 loss (see Appendix C).

<u>12-13-63</u> The transformer loss at the Portsmouth Gaseous Diffusion Plant, in which the deluge system failed, resulted in a $244,800 loss (see Section A7)

<u>6-21-67</u> A flammable liquids fire in a radioactive materials cell at Richland, Washington resulted in a $155,000 loss. The manually activated water spray system controlled the spill fire with the aid of fire department hose streams. Detection and alarm were by operators. Fire department was called by special emergency phone system. Cleanup operations contributed to the cost.

<u>1-3-78</u> This $200,104 loss at the Paducah Gaseous Diffusion Plant activated 25 heads on the hydraulically calculated sprinkler systems (see Appendix C).

<u>11-21-78</u> This $243,000 garage fire at Richland was controlled by the 149 ordinary hazard, wet-pipe heads in the fire area (see Appendix C).

APPENDIX E

THE MAJOR NON-FIRE LOSSES

There were 13 incidents that resulted in losses of $5,000 or more. The maximum loss was $96,000 and the mean loss in this range was $21,863. These incidents, while comprising about 3 percent of the number of non-fire incidents in the survey, account for almost 80 percent of the losses.

All incidents over $5,000 are noted below in chronological order:

1/29/66 Freezing weather in South Carolina resulted in a number of incidents totalling $56,000 in losses. Unfortunately, the total loss was ascribed to the single-days weather. A number of systems were involved, including other than sprinkler systems, so losses in this study are somewhat overreported.

1/17/72 An Ohio laboratory suffered major damage to a penthouse sprinkler system (type unspecified) when attic temperatures fell below freezing for a prolonged period. Loss was $5,700.

10/5/76 A contractor employee at the Los Alamos National Laboratory site left open piping on a preaction system. Laboratory equipment was damaged to the extent of $6100 when water was let into the system for test.

11/28/76 Building heat failed in sub-zero temperatures in New Mexico, resulting in freezing of heating coils and wet pipe sprinklers (both heads and pipe ruptured). Loss was $16,000.

11/29/76 The same cold snap caused a boiler room wet pipe system to freeze at the same site for a $5900 loss.

1/1/77 An Ohio Laboratory, an outside construction contractor left a crawl space open over a sub-zero weekend. A wet pipe sprinkler system froze and ruptured piping. Some water ran through a plaster ceiling, depositing calcium and other impurities on contacts and printed circuit boards in a computer for a loss of $22,000.

1/17/77 A World War II frame structure, built as a mess hall and subsequently converted to a museum and then offices, had many blind spaces and concealed piping. Inadequate heating resulted in rupture of heads and piping during a prolonged cold spell in this Tennessee area, resulting in about $10,000 damage to the system and various offices.

1/30/77 Freezing of a deluge system pipe on an Ohio Laboratory filter bank allowed the system to activate. Most of the $6254 was cleanup costs for the contaminated filter bank area.

11/12/78 Water was accidentally admitted to a dry system being installed at Idaho. The approximately $20,000 loss in an employees change room was sustained by the installing contractor.

12/10/78 This $13,000 loss at an Albuquerque facility resulted when a water closet (3'x5') in an improperly drained low point in a dry system froze and allowed water to spray out computer components.

1/2/79 $6200 damage to an unspecified type of system at a National Laboratory resulted from freezup of a system.

4/18/80 Probable actuation of a manual deluge system trip resulted in about 2,000 gallons of water discharging into a hot cell. Cleanup and disposal of contaminated water was the principal cost element. $36,000

9/11/80 A new, wet pipe system was under hydrostatic test in a closet (3'x5') area. Pressure was left on overnight and a loose fitting allowed water to discharge on a computer. The fact that the waterflow alarm had not yet been installed contributed to the $96,000 loss. This was the largest non-fire loss involving a sprinkler system.

Appendix F
Bibliography

A number of AEC/DOE publications relate to sprinkler protection and reliability. A number of those relevant to topics discussed in this paper are listed in chronological order below. A brief note regarding the content of each is also included.

AECD-3737 Tests to Determine Safe Operating Conditions for Use of Water Spray Protection for Energized Electrical Transformers by W. L. Richardson, K-25 Plant, January 7, 1955.

Describes tests made following a 1952 incident and concludes that NFPA clearances are highly conservative.

Fire Tests of Automatic Sprinkler Protection for Oil Spill Fires, (Declassified) FMRC, September 9, 1957, 39 pages.

At the request of the AEC, the Factory Mutual Research Corporation conducted a series of fire tests at their facilities at Norwood, Massachusetts to evaluate the use of sprinklers in gaseous diffusion plants, against fire in lubricating oil fires.

Fire tests were made involving oil, at elevated temperatures, covering 2100 sq. ft. of floor, also at elevated temperatures, and employing various methods of ignition.

Special Report on the Use of NBFU No. 15 Water Spray Systems for Fire Protection, Plant Engineering, Lawrence Berkely Laboratory, July 1961.

iscusses differences between calculated and ordinary systems.

Experience Gained by Paducah Fire Indicates Need for Caution in Selecting Sprinkler Heads Ratings, AEC Serious Accident Bulletin No. 215, January 17, 1964.

Notes differences in operating temperatures among similarly rated heads.

Automatic Sprinkler Systems Cost Data, monograph by W. Maybee, San Francisco Operations Office, March 2, 1964.

Summarizes 15 system installations by area, cost per head and cost per square foot (at that pre-conputer time, ordinary hazard systems averaged 47¢ per square foot and hydraulically calculated systems 77.5¢ per square foot).

SAN Guide for Inspecting Automatic Sprinkler Installations, by W. Maybee, San Francisco Operations Office, March 1967.

Inspection notes for non-fire protection engineers inspecting sprinkler systems.

Water and Electronics Can Mix, D. J. Keigher, Richland Operations Office, Fire Journal, November 1968.

Describes AEC experiences with water in electronics areas.

Y-DA-3318 Sprinkler Demonstrations at the Oak Ridge Y-12 Plant, L. M. McLaughlin, May 15, 1970.

Describes sprinkler tests in gloveboxes and on various combustible metals.

Y-1801 Evaluation of Multilevel Sprinkler Systems and Container Materials for Fire Protection by High Rack Storage, by W. G. Butturini, R. J. DeMonbrun and W. J. McLaughlin, Y-12 Plant, 1971.

Describes tests of rack sprinklers and container coatings in various configurations.

KY-L-591 Lube Oil System Protection, by M. E. Schapbach and W. R. Rossmassler, Paducah Gaseous Diffusion Plant, January 25, 1972.

Discusses lube oil protection features, including sprinklers. Of three fires, two were extinguished by operators and one by three sprinkler heads.

Y-JA-90 Information Bulletin, Cooling Tower Hardware and Its Corrosion, by J. R. DeMonbrun, Y-12 Plant, (paper delivered at Joint AEC Fire Protection Conference, Albuquerque, NM, March 21-23,1973).

Describes 15-years experience with different materials and protective systems.

Y-JA-91 Cooling Tower Sprinkler Systems Final Report, by J. R. DeMonbrun and J. A. Parsons, Y-12 Plant, (see Y-JA-90).

Describes problems and corrective actions covering 15-years experience.

Y-JA-92 Multi-Cycle Systems, Experiences and Costs, J. R. DeMonbrun, Y-12 Plant (see Y-JA-90).

Cost data and installation-test-maintenance experience.

J-JA-96 Experiments with Sprinkler Head Canopies for Fire Protection, by J. R. DeMonbrun and J. W. McCormick, Y-12 Plant, July 2, 1973.

Describes canopy modifications affecting flow patterns.

Y-1916 Fire Sprinkler Network Analysis Program, J. T. Blackmon and E. T. Stickle, Y-12 Plant, April 2, 1974.

Describes Fortran IV hydraulic design system.

Sprinklers - A Question of Overdesign/Underdesign, by R. F. McNair, The Calibre Group, October 22, 1975, paper delivered at October 22, 1975, conference of Albuquerque Operations fire protection personnel.

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Automatic Sprinkler Corrosion Protection, Monograph by J. W. McCormick, August 23, 1976.

Describes Y-12 Plant-developed fluorelastomer coating for multiple-acid vapor atmospheres.

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Uses fault-tree methodology to assess reliability of a modified preaction sprinkler system.

Sprinkler Design-System Drainage, Oak Ridge Operations, Memo September 28, 1978.

Notes problems with allowable drain plugs for sloped lines. Requires all lines to be drained to main drain valve, or auxilliary valves.

Mercury Check Valve Summary, HQ Memo of October 23, 1979.

Summarizes field investigations of problem reported by manufacturer with photos and list of corrective actions at various DOE sites.

Sprinkler Heads Test, H. Ford, Lawrence Livermore National Laboratory, 1979.

A series of tests on various painted heads was run, confirming that all painted heads should be replaced.

K/C-1316 Volume XXII, Part 1 Gaseous Diffusion Complex Reliability Assessment-Fire Protection, by J. R. Hutton, February 14, 1980.

Evaluates overall condition, reliability and upgrading actions for sprinkler system.

Sprinkler Failure-Central On-Off Type, Memo June 5, 1980, by P. E. Phillips, Nevada Operations Office.

Describes failure and possible scenarios.

K/C-1316 Volume XXII Part 2 Gaseous Diffusion Complex Reliability Study - Fire Protection System, by J. D. Hoogesteger, J. R. Hutton and J. D. Nichol, June 13, 1980.

Part of an overall reliability study this discusses factors affecting reliability of all GDP fire protection systems.

A Rationale for Sprinkler Operation in the--(X-326 Building), Battelle Columbus Laboratory study, 1980.

Discusses operation of sprinklers in criticality-potential area. Concludes (for all areas of study) that sprinklers should not be deactivated for criticality considerations.

"Clean Rooms - Another Fire Protection Problem," Part I, Fire Technology, Vol. 3, No. 4, November 1967, Donald J. Keigher, AEC-RLO.

Describes clean room fire problems and application of automatic sprinkler systems in this special occupancy.

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