AEC-001

REPORT OF INVESTIGATION COMMITTEE ON AEC INVESTIGATION OF ACCIDENTAL X-RAY EXPOSURE AT HASL, NY ON FEBRUARY 4, 1974

(Conclusions and Recommendations)

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I. SUMMARY

I. Summary

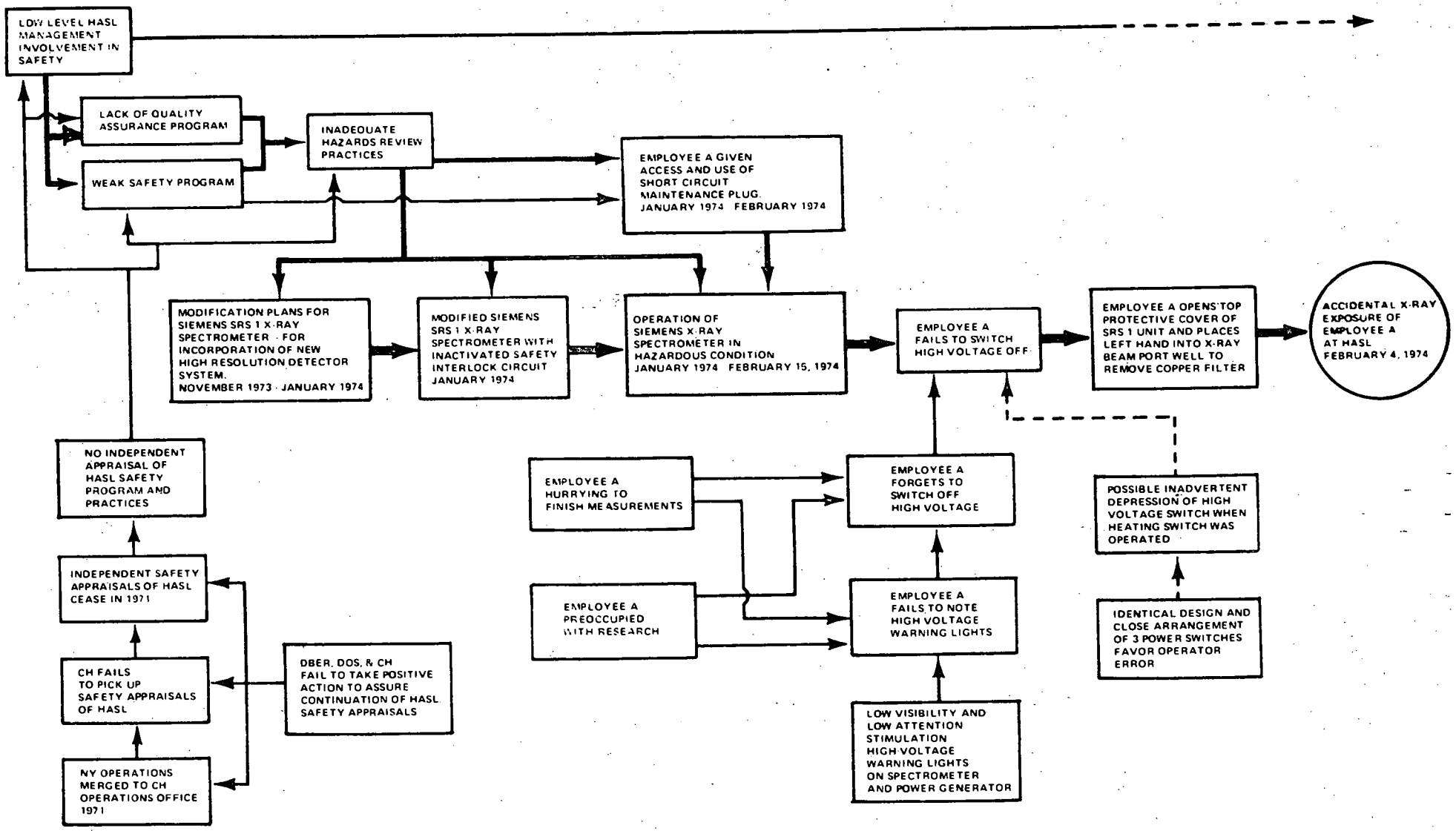
On February 4, 1974, a radiochemist employed at HASL was accidentally exposed to the x-ray beam of a modified Siemens X-Ray Spectrometer while engaged in x-ray fluorescence analysis of metals. A single exposure of the left hand resulted in a dose of 2400 rad to 4800 rad, causing severe injuries that will probably result in loss of the tip of the index finger and loss of some tissue and function of other fingers. Probable exposure to the head, eyes and upper body did not exceed 50 mR. There was also a probable single exposure of several rad to the right thumb that produced no injury.

The immediate cause of the accident was the operation of the spectrometer in a modified configuration that caused inactivation of the safety interlock circuit and allowed x-ray tube operation with the protective top cover of the unit open. The employee inadvertently put his left hand close to the x-ray beam port thinking that the unit was switched off. A series of management oversights at both field and Headquarters levels contributed to the accident. At HASL, weak quality assurance and safety programs that do not provide for systematic, timely safety review of ongoing, proposed, new, or modified operations or equipment were contributory. Headquarters and CH failed to take positive action to assure the continuation of the independent safety appraisals of HASL that ceased in 1971 when NY was merged to CH. Human engineering factors related to poor location and visibility of warning lights were also contributory, and the design of the power control switches may have been contributory.

II. FLOW CHART

II. Figure 33. CAUSAL FACTORS FLOW CHART

ACCIDENTAL X-RAY EXPOSURE AT HASL
FEBRUARY 4, 1974



Recommendations focus on the areas of Management, Quality Assurance and Safety Programs, and Equipment Design and Operation. These recommendations call for development of effective quality assurance and safety programs at HASL to assure timely reviews of proposed, ongoing, new, or modified operations or equipment, reinstitution of independent safety appraisals of HASL, restoration of the integrity of the spectrometer's safety interlock circuit, and improvements in the unit's power control and warning systems.

III. ANALYSIS

III. Analysis

A. Causal Factors

A series of causal factors operating for various periods of time combined sequentially to produce the accidental x-ray exposure at HASL on February 4, 1974. Figure 33 is a Flow Chart depicting the sequence of Causal Factors.

The hazards review of the modifications of the Siemens SRS 1 x-ray spectrometer consisted only of informal, undocumented discussions between the researcher (employee A), his Division Director and the Instrumentation Division. The modified SRS 1 Unit was not even subjected to a radiation safety survey. Despite the warnings in the Siemens SRS 1 Operating Instruction Booklet [13] the researcher was given access to the short-circuit plug and was free to use it as he wished. Thus, the stage was set for this accident. The spectrometer was allowed to be modified and operated in a dangerous condition.

A combination of confusion and lack of positive action on the part of DBER, DOS and CH allowed the independent safety appraisal responsibility for HASL to "fall through the crack," and these appraisals ceased after the merger of NY to CH in 1971. Thus, the opportunity for the detection of poor hazards review practices and hazardous operation of the spectrometer at HASL, at this next level of safety review, was lost.

The warning system design of the SRS 1 spectrometer and its related power and counting units did not provide the operator with a signal of sufficient visibility and attention getting characteristics. The warning light on the SRS Unit is quite small and located below the operator's eye level. The larger warning light on the Power Unit is recessed under the top of the unit and located at such a low level that

it cannot be seen by an individual standing erect in a position to operate the units. The operator must bend down to see the warning light.

The identical design, close side-by-side arrangement, and poor visibility location of the three power control switches favor operator error. It was demonstrated that inadvertent depression of the High Voltage push-button switch simultaneously with the intended depression of the Heating pushbutton switch can result in the failure to switch off the high voltage to the x-ray tube even though the Heating switch is fully depressed. Characteristic "clunking" relay sounds can also be heard in this mode of switching and these sounds could give an operator a false cue that the high voltage had been switched off. The Committee feels, however, that it is unlikely that this kind of operator error was involved in the accident under investigation. There is evidence supporting the probability that Employee A simply forgot to switch off the high voltage. Employee A's standard and habitual routine in switching off the high voltage was to first turn the kV and mA step switches down to their minimum settings. He consciously did this in order to prolong the life of the x-ray tube. If he simply forgot to switch off the high voltage, then he also would not have taken this first step to turn the kV and mA step switches down to minimum power settings. The Committee's dosimetry studies and clinical analysis of the exposure injuries indicate that the x-ray tube was operating in the 50 kV to 60 kV range. Therefore, it is felt that since Employee A failed to take this first step of lowering the power settings, he most probably simply forgot to shut off the power after the last series of test measurements before the accidental exposure.

Operator preoccupation with the research was quite high at the time of the accident event, and the operator was also hurrying to finish a series of measurements before the end of the work day. These factors combined with the poor warning system design factors to cause the probable operator error of forgetting to switch the high voltage off before opening the protective top cover and removing the copper filter.

It is clear from the factual history of this accident that Employee A thought that the power to the x-ray tube was off at the time he introduced his left hand into the x-ray beam port well to remove the copper filter.

It is also possible that Employee A did switch off the high voltage before he left to go to the computer room, and that someone accidently depressed the High Voltage switch while he was absent either by bumping into it, by leaning against it, or by brushing against it. The recessed location of the High Voltage switch leads the Committee to feel that this is highly improbable. However, the lack of a safety guard over the High Voltage switch makes such accidental operation possible. Also, if Employee A had switched off the High Voltage in his routine manner, he would have set the kV and mA step switches to their lowest power settings (20 kV and 6 mA). Then, if someone accidentally operated the High Voltage switch, the x-ray tube would have been operating at a low output. As pointed out before, dosimetry studies indicate that the x-ray tube was operating in the 50 kV to 60 kV range.

There is considerable room in the x-ray beam port well for side to side movement of the two fingers holding the plastic "handle" on the copper filter. Just a slight movement is enough to displace the

copper filter and expose a part or all of the x-ray beam port hole. The offset position of the hole toward the front of the SRS Unit greatly favors the left index finger getting directly over the bare beam port hole when the operator is standing at the left front corner of the SRS Unit and reaching into the beam port well with the left hand.

The fact that the lesions (injuries) of the left hand are congruent with the hand and finger positions described and demonstrated by Employee A convinces the Committee that this was how the actual exposure of the left hand took place.

The Committee felt that the training given to Employee A in operation of x-ray spectrometer devices was adequate for units protected by radiation safety interlock circuits.

B. Nature of the Exposure

There are compelling reasons to believe that Employee A's injuries resulted from a single exposure. These include (a) dosimetry studies that indicate a high enough single dose to the hand and fingers to account for the injuries; (b) the compatibility of the clinical evaluation of the injuries with the dosimetry studies; (c) the fact that the event of the afternoon of February 4, 1974, is the first and only time that Employee A was ever surprised to find that the x-ray tube was operating when he though that it was off; (d) the clearly defined congruency of the hand and finger lesions (injuries) with the method demonstrated by Employee A in removing the copper filter; and (e) the fact that Employee A performed only one removal of the copper filter.

Before removing the copper filter, Employee A had to open the beam port cover. Demonstration by the Committee verified that Employee A's description of how he opened this cover was the easiest and most natural way of doing it. It is most probable, therefore, that the right thumb was the only part of the hand exposed in this operation. Dosimetry calculations indicate that a dose of several rad would be delivered to the thumb in the 1 to 2 seconds required to open this cover.

There is considerable evidence indicating that Employee A did not receive any significant exposure to any other parts of the body: (a) He was wearing a film badge and it did not show any significant exposure. He always wore his film badge over the left breast or on rare occasions over the middle of the upper chest. The GSA HASL guard records for February 4, 1974, do not show the issuance of a temporary badge to Employee A, as would have been required had he forgotten to bring his identification badge with its attached film badge to work that day; (b) Employee A is quite clear in his recollection of how he actually removed the copper filter from the SRS Unit and he does not recall leaning or bending over the beam port well. Further, he points out that it was not necessary to bend over in order to see the copper filter, and this fact was verified by the Committee. If Employee A had leaned over the open x-ray beam port well, the film badge on the anterior chest would have registered a significant expsoure; (c) Calculations based upon the geometry and strength of the x-ray field emerging from the open beam port well and specimem chamber indicate an exposure of 20 to 50 mR at eye level, and less at upper body levels, to Employee A standing erect at the left front corner of the SRS Unit.

C. Effects of the Exposure

1. Effects on Employee A

Clinical evaluation of the injuries to the left hand indicate a probable loss of the tip of the index finger and possible loss of tissue and function of other fingers. No clinical consequences are expected from the exposures to other parts of Employee A's body. Employee A gave a clear description and demonstration of the position assumed by the left hand and fingers in removing the copper filter from the narrow confines of the open specimen chamber and x-ray beam port well. The Committee verified that this position was the easiest and most natural hand position, and that other positions made it either very difficult or impossible to get the hand into the beam port well. A comparison of the injury lesions on the hand with the hand and finger position described and demonstrated by Employee A, shows that the distribution of the lesions is congruent with the established hand position. Figures 34 to 36 show pictures of a hand moulaged to simulate the actual distribution of the lesions. These pictures demonstrate the congruency of the lesions with the established hand and finger position. Note that Figure 36 explains why the back of the third finger received no serious injury. It was effectively shielded by the copper filter. Dosimetry studies have shown that the copper filter attenuates the x-rays by a factor of 10, although it does cause some hardening.

2. Effects on Others in HASL

There is reason to believe that no one else present in HASL on February 4, 1974, received any significant exposure either while Employee A was removing the copper filter during operation of the x-ray tube, or during the approximate 15 minute period that the x-ray tube was operating unattended. The fact that Employee A remembers closing the beam port cover and the top protective cover of the SRS Unit after removing the copper filter on February 4, 1974, weighs against any significant stray radiation from the Unit while it was operating unattended for about fifteen minutes. Even if these two protective covers were left open, survey studies indicate that no significantly dangerous radiation would occur around the SRS Unit. An employees' locker room represents the most sensitive adjacent area (See figure 1). However, it is located behind a concrete block wall. Surveys made in this locker room while the SRS Unit was operating with the top cover and beam port cover open show nothing above background radiation. The small work bench behind the Counting Unit is used by Employee A for preparing specimens. It is inconveniently placed, and no one else ever uses it.

All of the medical members of the Investigation Committee are in agreement that Employee A is receiving good medical care and that his attending physician has demonstrated excellent skill and judgment.

Figure 34. LEFT HAND MOULAGE TO SIMULATE THE X-RAY INJURIES

Figure 35. MOULAGED LEFT HAND SHOWING FINGER POSITION AT TIME OF EXPOSURE. VIEW AS SEEN FROM X-RAY BEAM PORT.

Figure 36. MOULAGE LEFT HAND HOLDING THE COPPER FILTER.

The Committee feels that the HASL Medical Consultant should have participated more deeply and actively in providing advice to the Director of HASL and to Employee A's attending physician. The Consultant's advice not to debride the injuries was of great value. However, the Committee feels that the Medical Consultant should have seen Employee A and consulted personnally with his attending physician in order to determine whether or not there was a need for further consultative support by someone experienced in the management and treatment of radiation injuries. This event represents the first time that the medical consultant was called for an in-house HASL accident in his 14 years as a HASL consultant.

IV. CONCLUSIONS

IV. Conclusions

A. On February 4, 1974, Employee A was accidentally exposed to the x-ray beam of an x-ray spectrometer at the HASL.

1. This exposure caused severe injuries of the left hand that will probably result in loss of the tip of the index finger and possible additional loss of tissue and function of other fingers.
2. The injuries to the left hand were the result of a single exposure.
3. There was probably a single exposure to the right thumb of several rad that produced no observable injuries.
4. There was probably an exposure of 20 to 50 mR to the eyes and head, and somewhat less to the upper body.
5. The exposures to parts of the body other than the left hand are not expected to produce any clinical consequences.
6. Dosimetry studies indicate a maximum dose range to the finger tips of the left hand of 2400 rad to 4800 rad for the probable exposure time range of 2 to 4 seconds.
7. The clinical appearance and course of the lesions is compatible with the above dose assessment.

B. The probability that the accident event caused any significant exposure to any other individuals present in the HASL on February 4, 1974, is extremely remote.

C. The immediate cause of the accidental exposure was the operation of the Siemens X-Ray Spectrometer in a modified configuration that caused inactivation of the safety interlock circuit and allowed x-ray tube operation with the protective top cover of the unit open.

D. A series of management oversights contributed to the accident.

1. HASL safety management oversights.

a. HASL's quality assurance, safety program and hazards review efforts are weak and incomplete, and fail to provide for systematic, timely, safety and hazards review of ongoing, proposed, new, or modified operations or equipment covering the planning, procurement, implementation, modification, and operational phases of the total life span of projects and programs. Specific written safety procedures for the subject Siemens X-Ray Spectrometer and for other HASL equipment are lacking.

b. The HASL safety policy is narrow in scope. It does not provide for documented independent and interactive safety assessments of laboratory activities at levels commensurate with the risks.

c. Implementation of the safety program does not assure objectivity in the review or inspection of programmatic activities.

d. The safety program does not provide periodic radiation safety surveys of the subject x-ray spectrometer unit, and the unit was not surveyed after its modification.

e. The HASL film badge dosimeter program does not provde a substitute film badge for an employee who has been assigned a film badge and who inadvertently reports to work without it.

f. Management support of the safety program is not very active.

2. Headquarters and Chicago Operations management oversights.

The independent periodic appraisals of safety and safety management at HASL ceased subsequent to the merger of NY functions

to CII in 1971, and DBER, DOS and CII failed to take positive action to assure the continuation of these appraisals.

E. Operator errors contributed to the accident.

1. Probable failure to shut off the high voltage to the x-ray tube upon completion of the last series of tests prior to the accident.
2. Failure to notice the red warning lights on the x-ray spectrometer and its associated power generator unit.

F. Human engineering factors contributed to the accident.

1. The location and size of the red high voltage warning lights on the spectrometer and its associated power generator unit failed to provide the operator with an adequate, high attention stimulation warning signal.
2. The identical design, close side by side arrangement, and poor visibility location of the three power control switches on the power generator unit favor operator error.
3. The location, small size and similarity of the symbols associated with the three power control switches on the power generator unit favor operator error.
4. Although accidental operation of the High Voltage switch is unlikely because of its recessed location on the power generator control panel, the lack of a guard over this push-button switch makes such accidental operation a possibility.
5. If the operator inadvertently depresses the High Voltage push-button switch as he is depressing the Heating switch, then the high voltage may not be switched off even though the Heating switch has been fully depressed.

G. Human factors contributed to the accident.

1. Employee A was eager and in more of a hurry than usual to complete another series of test measurements before the end of the February 4, 1974 working day.

2. Employee A was probably more preoccupied than usual with his research at the time of the accident.

H. Medical management and treatment are adequate.

Employee A is receiving excellent care and treatment from his attending physician, Dr. K. Kalemkeris, who has demonstrated sound clinical judgment and ability.

I. The HASL medical consultant should have participated to a greater degree in providing advice to the injured employee's private physician and to the Director of HASL.

V. RECOMMENDATIONS

V. Recommendations

A. Equipment Recommendations

1. That before any further operation of the subject Siemens X-Ray Spectrometer, protective enclosure panels be designed and provided that (a) do not violate the originally designed safety interlock circuit, (b) physically enclose all of the modification components, and (c) include all of the modification components within the protection of the safety interlock circuit.
2. That any proposed modifications of the subject spectrometer or its operating procedures be given a thorough safety review prior to their implementation.
3. That a "High Voltage" warning light be provided to give the operator a high attention stimulation signal that the x-ray tube is operating. This warning light shall be highly visible from all operating positions and from all parts of the room. It should be large, located at the operator's eye level, and preferably should be a flashing light. It should be wired in series with the low voltage safety interlock circuit.
4. That a scintillation-scaler unit be installed in the Counting Unit that will give a continuous counting light display at all times that x-rays are being generated by the spectrometer in order to provide additional warning to the operator.
5. That the three power switches on the control panel of the power generator unit be further separated from each other, and that the High Voltage switch be provided with a distinctive guard cover that is spring loaded to the guard position.

6. That power switch symbols of higher visibility and more distinctive symbology be provided.

7. That the short-circuit bridging terminal be relocated to a high visibility location, and that the short-circuit plug be provided with a high visibility, distinctive, warning flag.

B. Management Recommendations

1. That the HASL Quality Assurance and Safety Programs be improved and broadened in scope to:

   a. Provide for active management support and involvement at the levels necessary to assure the effectiveness of the programs.

   b. Provide an effective safety management system that will assure systematic, timely safety and hazards reviews of on-going, proposed, new, or modified operations or equipment, covering the planning, procurement, implementation, modification, and operational phases of the total life span of projects and programs.

   c. Assure objectivity in the review and inspection of programmatic activities.

   d. Expand the radiation safety activities to specifically include the subject spectrometer unit.

   e. Assure that a substitute film badge dosimeter be provided to an employee who is assigned a film badge dosimeter and who inadvertently reports to work without it.

   f. Restrict the use of the SRS 1 spectrometer short-circuit plug to the maintenance requirements authorized by the manufacturer.

g. Place the SRS 1 spectrometer short-circuit plug in protective custody and effectively limit access to qualified, authorized maintenance personnel.

h. Provide for an adequate medical consultant capability.

2. That the responsibility for independent periodic safety appraisals of HASL be clearly assigned by DBER, and that the program be implemented as soon as possible.

3. That DBER initiate a comprehensive management review of Quality Assurance at HASL to assure the adequacy and effectiveness of Safety Management and Policies.

4. That a Safety Bulletin highlighting the causal factors of this accident be prepared and distributed AEC-wide by DOS. This bulletin should emphasize the continuing high accident rate associated with x-ray spectrometer and diffraction apparatus, and the fact that by-passing of safety interlock circuits is an almost universally found immediate cause of such accidents. The Safety Bulletin should also be issued to the Bureau of Radiation Health, FDA, HEW.

5. That DOS initiate a survey (a) to develop an inventory of the number, type and location of all x-ray spectrometer and diffraction units throughout AEC operations, and (b) to determine that local Safety Management Programs effectively include safety reviews of such equipment and operation procedures.

6. That AEC develop design and operating standards for x-ray spectrometer and diffraction devices. This document will provide safety requirements and performance criteria for procurement, acceptance and operation of new or modified equipment.

VI. BIOGRAPHICAL DATA

VI. Biographical Data on Employee A

The employee involved in the accidental x-ray exposure at HASL on February 4, 1974 is Mr. Colin G. Sanderson.

Date of Birth: September 29, 1935 Place: New Hyde Park, N.Y.

Education: B.S. - Lehigh University, 1958.

Previous Experience: 1958 - 1962 Lever Bros. Co. - Research Chemist

1962 - 1966 Isotopes, Inc. - Group Leader

AEC Employment: May 23, 1966 GS-12.

Promotion: November 1967 GS-13.

He is married and has six children, and resides at 19 Meadow Lane in Norwood, New Jersey.

VII. APPOINTMENT MEMORANDUM

VII. Committee Appointment Memorandum

UNITED STATES
ATOMIC ENERGY COMMISSION
WASHINGTON, D.C. 20545

FEB 2 1 1974

William R. Albers, M.D.
Occupational Health Physician
Division of Operational Safety

INVESTIGATION OF POSSIBLE RADIATION EXPOSURE AT THE AEC HEALTH AND SAFETY LABORATORY, NEW YORK

You are hereby appointed as Chairman of a committee to investigate the possible radiation exposure of an employee of the HASL. The following additional personnel are appointed as members of the committee:

Dr. Roy Maxwell, DBER
Mr. James E. McLaughlin, HASL
Mr. David Schweller, BHO

In addition, the following personnel are designated as consultants to the committee, to be utilized as required and requested by the Chairman:

Dr. Neil Wald, Univ. of Pittsburgh.
Dr. Clarence Lushbaugh, ORAU

The investigation and reporting are to be conducted in accordance with AECM 0502 insofar as circumstances associated with this subject permit. The report should, of course, fully cover and explain the technical elements of the causal sequence(s) of the occurrence. The report should also describe the management systems which should have, or could have, prevented the occurrence, e.g., the safety or hazard review system, the quality assurance program for safety (including the monitoring of actual operations). Appropriate recommendations for improvement of the management systems will be required.

James L. Liverman
Assistant General Manager
for Biomedical & Environmental
Research & Safety Programs

VIII. SIGNATURES

VIII. SIGNATURES OF INVESTIGATION COMMITTEE:

William E. Ahern, M.D., Chairman

Roy L. Caldwell, Ph.D.

James E. McLaughlin

David Schlessinger

Neil Wald, M.D.
Consultant

C. C. Lushbaugh, M.D.
Consultant

IX. ACKNOWLEDGMENTS

IX. Acknowledgments

The Investigation Committee wishes to extend its appreciation for the contributions of the following individuals who have expended a great deal of time and effort to assist the Committee in accomplishing a thorough investigation of the unfortunate accident event:

HASL Staff

Robert Graveson
Melvin Cassidy
Donald Freeswick
Marvin Copes
Robert Sanna
Gail Burke
Ferenc Hajnal

Brookhaven Laboratory

Ronald Withnell
Carl Walther
Arthur Swenson
Robert J. Walton
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Gattett Holt